

RADIO PHYSICS COURSE

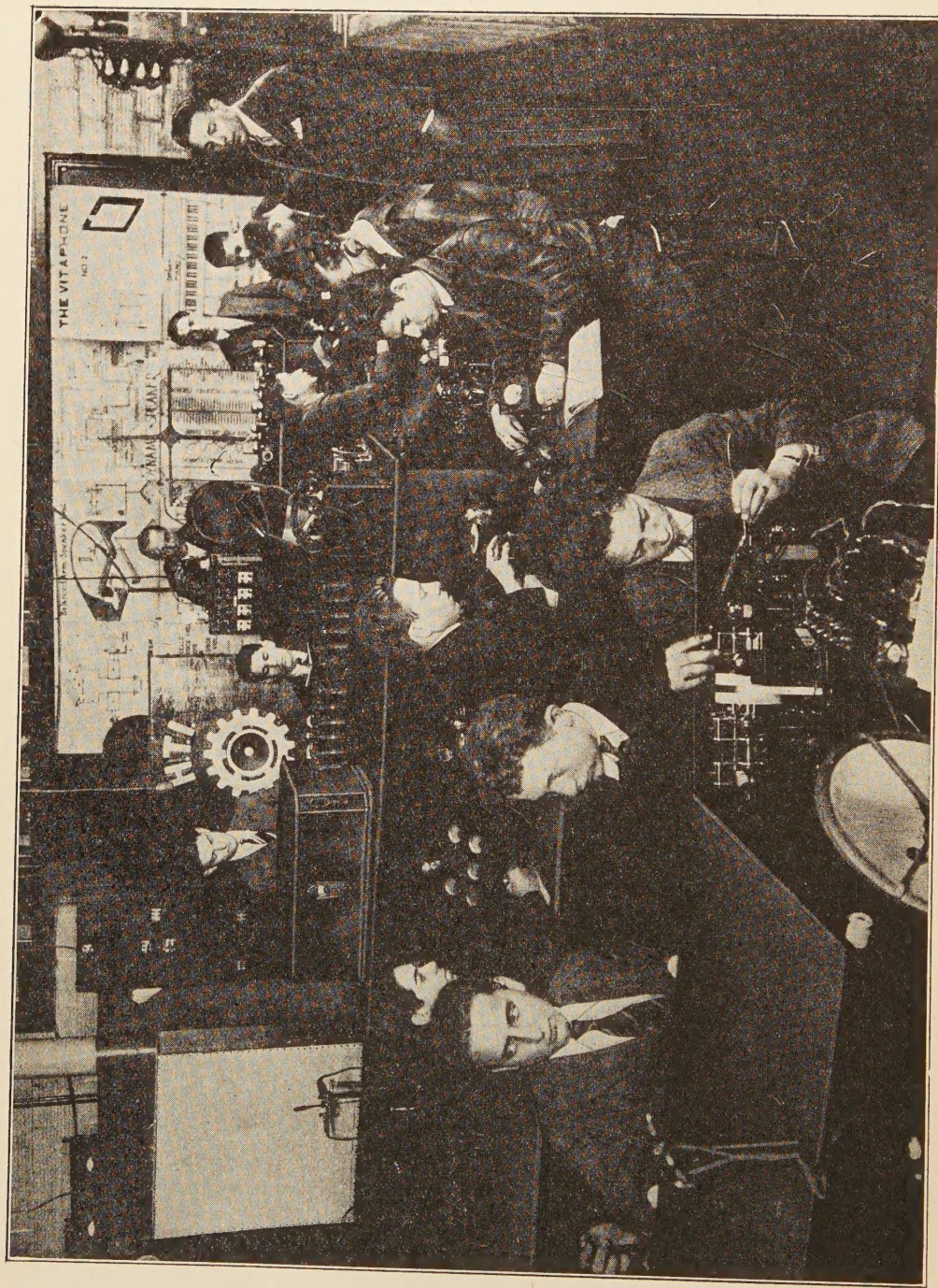
BY

ALFRED A. GHIRARDI



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A Radio Laboratory in a High School

RADIO PHYSICS COURSE

An Elementary Radio Text Book
For
Students, Set Builders and Servicemen

BY

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P R E F A C E

The purpose of this book is to furnish a complete elementary text on the subject of radio telephone receiving, for use in high schools and by custom set builders and those thousands of technical and non-technical persons who desire to gain an insight into the working of their radio receivers, either for their own knowledge and satisfaction or as a means of earning a livelihood.

The title "Radio Physics" has been applied in the sense that physics is mainly an explanation of common things. Radio Physics is then an explanation of the common things in radio. The book has been arranged so as to be suitable for use as a classroom text. The topic sections are numbered for easy reference. The Radio Physics Course in its present form is the result of the requests of many readers of *Radio Mechanics* and *Radio Design* magazines, in which the course was originally published as a series of articles.

In the preparation of the text the pupil has been kept constantly in mind. Involved mathematical explanations have been avoided. An attempt has been made to present the subject matter in as simple language as possible.

If some of the explanations seem unduly long and detailed, it is because the writer has found, by practical experience in teaching the subject in classroom and laboratory, that those particular topics require such explanation for proper understanding by the novice. The order of topics and illustrations has been selected with the purpose of leading the pupil into the subject in the most logical manner. The use of over 350 carefully planned illustrations prepared personally by the writer is in accordance with his firm conviction that a good illustration tells more than several hundred words.

A short review of the theory of simple D.C. and A.C. circuits is given more as a simple review for those who have already studied this subject than as an instruction text for the novice. It is evident that the study of elementary electricity and magnetism cannot be covered completely in a text devoted to radio. For those who wish to study seriously along these lines the writer recommends any of the excellent elementary electrical texts, such as Swoope's *Practical Electricity*, Timbie's *Elements of Electricity*, etc.

The subject matter has been made as complete and up-to-date as was practically possible. The descriptions of modern electric receivers, A.C. screen-grid tubes, television, the "talkies," etc., have been included to give the reader up-to-date knowledge of the subject. Very little space has been given to descriptions of obsolete apparatus, as the growth of modern radio knowledge has been so rapid during the last few years that it was thought best to utilize the available space for study of those things most in use and worth while.

The physical principles underlying the apparatus described have been stressed whenever possible in order to tie up theoretical knowledge with its practical application.

The author wishes to express his thanks to the Pilot Radio and Tube Corporation and to the various manufacturing companies of electrical apparatus for

P R E F A C E

supplying the cuts of the apparatus illustrated. Many helpful ideas have been obtained from time to time from such publications as the *Bell Laboratories Record*, *Radio Broadcast*, *Radio News*, and *Radio Engineering* magazines.

The author also wishes to express his appreciation to his many former pupils, who have been of invaluable assistance in providing questions which were food for thought and explanation, to Mr. M. B. Sleeper and Mr. Robert Hertzberg for their criticisms and valuable help during the preparation of the text, and to Dr. Edgar S. Barney and Mr. W. W. Ker, who have ever been an inspiration in this work. Thanks are also extended to the editors of *Radio Design* for their kind permission to reprint all of the Radio Physics Course articles which appeared in that magazine.

ALFRED A. GHIRARDI.

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RADIO PHYSICS COURSE

CHAPTER 1.

STUDY OF SOUND, VIBRATIONS AND WAVES.

BROADCASTING SYSTEM — SOUND — SOUND WAVES — FREQUENCY — PITCH —
HARMONICS — MUSICAL INSTRUMENTS — SOUND SENSATION — RADIO, HEAT
AND LIGHT WAVES.

1. **BROADCASTING SYSTEM OUTLINED:** Radio broadcasting, as we know it today, has for its object the transmission of sound waves—speech or music—from central distributing points, called broadcast stations, over long distances to the homes of thousands of people. The distance over which sound can be transmitted directly is very limited. Even loud whistles or sirens can only be heard over distances of a few miles. An ordinary speaker's voice cannot be heard intelligibly over distances greater than a few hundred feet.

Consequently, some means other than the direct transmission of sound must be employed in modern radio broadcasting, where programs are to be sent over distances of thousands of miles. The great servant of man, electricity, provides this means and is the main factor in the ever-growing radio industry.

Instead of transmitting the sound or speech waves directly, as in the case of one person talking to another across a room, they are converted into corresponding electrical waves by suitable apparatus in the broadcasting station. These electrical waves are then radiated or sent out in all directions from the aerial of the station through the atmosphere for miles around, to the receiving aerials of listeners scattered over the entire country. The electrical waves striking the aerials of the receiving stations set up currents which flow through the receiving apparatus. The function of the receiving set is first to detect and strengthen or amplify these feeble currents and then to convert them back into sound waves similar to the original sound sent out from the broadcasting station.

Thus you see electricity can be employed as an intermediate agent, due to the fact that we are able to transmit certain electrical waves over long distances very easily through the atmosphere without wires, while it is impossible to do this with sound waves. Another valuable advantage of this method is that it makes it possible to have a number of stations broadcasting at one time and still be able to select the program from any one station desired, without interference from any of the others. It is this latter feature which makes practical our modern broadcasting system, wherein a large number of high-powered stations are operating at one time in the same locality, while the listener is able to select any one of them at will by tuning his receiver.

An outline picture of the system as described is shown in Fig. 1. Starting

at the left, the man who is speaking sets up sound waves which are converted into corresponding electrical current impulses by the microphone *M*. These current impulses are sent into the transmitting apparatus *B*, where they are combined with a special type of electric current. The resulting current, flowing in the transmitting aerial *A*, produces electric waves which are transmitted in all directions. At the receiving aerial *C* these waves set up electric currents which flow into the receiving set *R*. Here they are detected and amplified sufficiently so that when they are sent into the loud-speaker *L*, they are converted back into sound waves which are loud enough to be heard by the listener. This outline of the complete broadcasting system should be studied very carefully, since a thorough understanding of the main function of each unit will make the study of the subject interesting and simple.

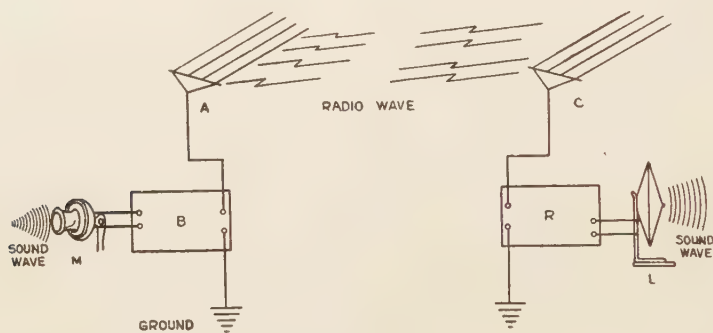


Fig. 1—Radio Broadcasting System, with Transmitter at Left and Receiver at Right

2. **SOUND:** Sound is the form of vibrating motion in an elastic medium which affects the auditory organs and produces the sensation of hearing. If we strike an ordinary bell so as to set it vibrating, it will produce a ringing sound. If the bell is large and the force with which it is struck is comparatively small, a series of slow vibrations are produced, resulting in a low note. If the bell is small and it is struck a strong blow, a series of rapid vibrations are set up, resulting in a high note.

When the bell vibrates, it beats the air in front of it and thus compresses it, while at the same instant the air in back of the body is rarified. These changes of pressure occur very rapidly and are transmitted from molecule to molecule of air in the form of expanding spheres of increased pressures and decreased pressures which travel outward in all directions. Any elastic body will transmit sound.

The speed or velocity with which sound waves travel depends upon the substances in which they are moving. They travel at the rate of 1084 feet per second in air, and about 18,400 feet per second in tempered steel. The velocity

of sound in various substances is given in the following table:

Substance.	Velocity of Sound in Feet per Second.
Air at 0° C.	1,084
Ash, along fibres	12,200
Brass	8,900
Copper	11,300
Cast iron	13,200
Glass	17,050
Lead	2,150
Mahogany, along fibres	14,500
Steel, tempered	18,400
Water, fresh	4,700
Water, salt	4,770

3. **SOUND WAVES:** When a person speaks, his vocal cords vibrate and set up tiny waves in the air which travel out in all directions. When these strike the eardrum of the listener, each pulse pushes a little against it, causing it to vibrate inward for each pulse, and outward again during each time between pulses. These vibrations actuate the auditory nerves, producing the sensation of sound, to which the brain responds. The number of these back and forth vibrations of the drum per second is the same as the number of pulses of the wave that arrive at the ear per second. That is, it is the same as the frequency of the wave. The higher this frequency, the shriller this sound seems to the brain. What we really hear then is the frequency, not the length of the wave. Frequency is always a more characteristic property of waves than the wavelength or distance one wave travels before the next starts, and will be used almost entirely in our discussion.

If we could devise apparatus for measuring the very small variations in air pressure caused by a simple sound wave at any particular point, we would find that these variations could be shown in picture form by the wavy line or curve of Fig. 2A, where vertical distances represent pressure and horizontal distances represent time. The axis or horizontal line represents the normal atmospheric pressure. When the sound wave comes along the pressure gradually increases to a maximum from *P* to *A*, then decreases from *A* to *B*, further to *C*, then increases again from *C* to *D* at which point the pressure is again the same as at the beginning. The next wave would continue similarly along *DEFGH*. point *A*, which is the crest of a wave, represents a point of condensation because at this point the air is condensed or compressed. Point *C*, which is at the hollow of a wave, is a point of rarefaction since at this point the air pressure is lessened or rarified.

It must be remembered that the actual pressure variations due to sound are very small. The variation due to the weakest sound which a person with average hearing can hear is in the order of .000000015 pounds per square inch. A painfully loud sound would produce a pressure variation of about .015 pounds

per square inch. A consideration of these figures shows that the human ear is an extremely sensitive and delicate instrument, since it is able to detect these minute pressures.

One of the most important distinguishing characteristics of a wave is its frequency. Any wave, a water ripple on the smooth surface of a pond, a sound wave, or a radio wave, consists of a succession of tiny impulses, moving along one after another. Simple waves, produced by a single to-and-fro vibrating motion, have a succession of regular crests and troughs as shown in Fig. 2A. A complete wave, or cycle as it is commonly called, is the part of the wave between one crest and the following similar crest. The length of a complete wave is called the wavelength. This may also be defined as the distance the wave disturbance moves while the vibrating body makes one complete vibration or cycle.

This term is similar to the familiar term "wavelength" assigned to broadcasting stations, with the exception that in that case it refers to the radio wave instead of the sound wave.

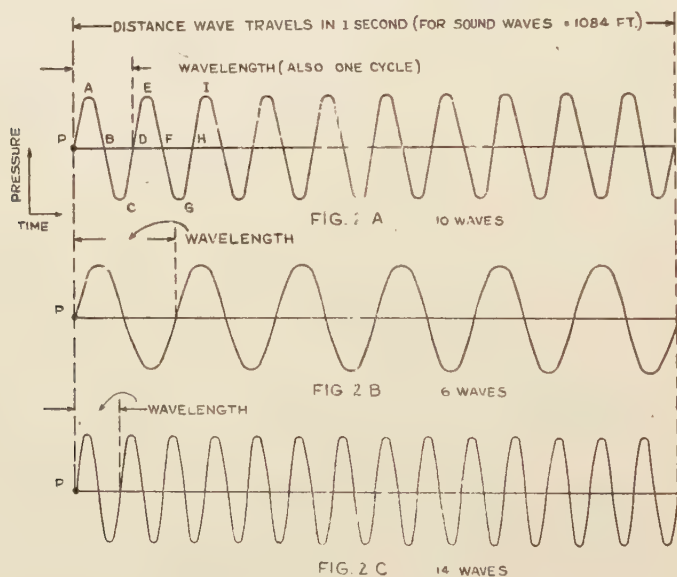


Fig. 2—Illustrating the Terms Cycle, Wavelength and Frequency

4. **FREQUENCY:** The number of complete waves or cycles that pass a fixed point in one second is called the frequency. To show the relation between these familiar terms more clearly, let us refer again to Fig. 2A. Suppose we have an instrument at point *P* which is producing the sound wave shown, having a frequency of 10 cycles, or complete waves, per second. Then in one second the disturbance will travel 1,084 feet (this being the velocity of sound waves in air), taking it to the end. In the space between here there are 10 complete waves, because 10 waves have been produced during the second. Therefore, the

frequency of the sound is 10 cycles per second. (Frequency is always expressed as the number of cycles per second.) The wavelength, will be equal to the total distance divided by the number of waves

$$\text{wavelength} = 1084 \div 10 = 108.4 \text{ ft.}$$

Now suppose the instrument at *P* is made to produce a sound wave of lower pitch, having a frequency of 6 cycles per second. This wave is shown in Fig. 2B. Then in one second the disturbance travels 1,084 feet as before, but since there are only six waves produced during this time interval, the length of each individual wave must be longer than in the previous case.

In Fig. 2C, the instrument is producing a wave of higher pitch, having a frequency of 14 cycles per second. In this case the wavelength is $1084 \div 14 = 77.4$ feet. It is evident from this illustration that as the frequency is decreased, the wavelength becomes greater, and as the frequency is increased the wavelength is less. The relation between frequency and wavelength is:

$$\text{Wavelength} = \frac{\text{Velocity of propagation}}{\text{frequency in cycles per sec.}}$$

The Greek letter λ (lambda) is used to represent the wavelength. Therefore
 for sound in air $\lambda = \frac{1084}{\text{frequency in cycles per sec.}} \dots\dots\dots (1)$

5. **PITCH:** When discussing sound, frequency refers to the pitch of the sound. Low pitched sounds like those of the bass violin are low in frequency; high pitched sounds like those of a flute are high in frequency. The normal human ear is able to detect sounds of frequencies as low as 16 and as high as 20,000 cycles per second. The frequencies of the sound waves created by the human voice during the course of ordinary conversation average 800 cycles. The actual limits of audibility depend of course on the sensitiveness of the hearing facilities of the individual as well as the intensity of the sounds themselves.

6. **HARMONICS:** Heretofore we have considered the most simple kinds of sound waves, that is, the "pure," fundamental, or sine-wave sound. This type of sound consists of but one vibration frequency and is very rare. A pure sound seems very flat when heard by the ear and has no musical value.

When we hear a musical sound, we have no difficulty in recognizing the particular kind of instrument that produces it. The sound of the violin, the piano, etc., each has its own peculiarities. The characteristics which enable us to assign a sound to its source are called the quality or timbre of the tone. The physical explanation of timbre is that most sounding bodies vibrate not only as a whole, but also in various parts, as does the string of a piano. The quality of a note is determined by the presence of tones of higher pitch, called harmonics, whose frequencies are multiples of the fundamental or lowest tone. To take a concrete case, let us consider the middle C string of a piano, Fig. 4. When this is set into vibration by striking the key, the whole string vibrates as a unit, producing vibrations of a fundamental frequency of 256 cycles per second. At the same time, the string also vibrates in parts, producing harmonic vibrations whose frequencies are exact multiples of the fundamental. That is, it will pro-

produce a second harmonic whose frequency is $256 \times 2 = 512$ vibrations, or cycles, per second, and possibly a fourth harmonic of 1,024 cycles. Thus, while the fundamental passes through one cycle, a harmonic passes through a number of cycles, depending upon which harmonic it is.

Higher harmonics than the fourth are seldom encountered in ordinary practice. Consequently the single middle C piano string is really producing four sound waves of different frequencies at one time. These four waves do not exist separately in the air, but combine to form a resultant wave which is different from any of its components. This is the wave which affects our ear.

To show how simple waves of differing frequencies can combine to produce a resultant wave different from each of them, let *A* in Fig. 3A

represent one cycle of a fundamental sound wave. The horizontal distances, called abscissa, represent time, and the vertical distances represent air pressure. Next *B*, that is, the wave of twice the frequency, is the second harmonic wave, emitted simultaneously with *A*. The resultant wave form is then represented by *C*. The wave *C* is

not symmetrical and does not resemble either of its component waves *A* or *B*. Also notice that its frequency is the same as that of the fundamental. Fig. 3B shows the resultant wave *C* produced by the combination of the same fundamental wave *A*, with its third harmonic *B*. Fig. 3C shows the resultant wave produced by the combination of the same wave *A* with its second, third and fourth harmonics.

The sound waves created during the course of human speech are very interesting due to their wide variation of form. In Fig. 3D, the wave form of the common vowel "A" is shown by the same graphical representation employed in previous illustrations.

7. MUSICAL INSTRUMENTS: The sounds created by musical instruments are practically always complicated and contain many harmonics. The violin produces a very strong third harmonic, while some of the notes produced by a flute are perhaps the purest of any sounds that are generated by musical instruments.

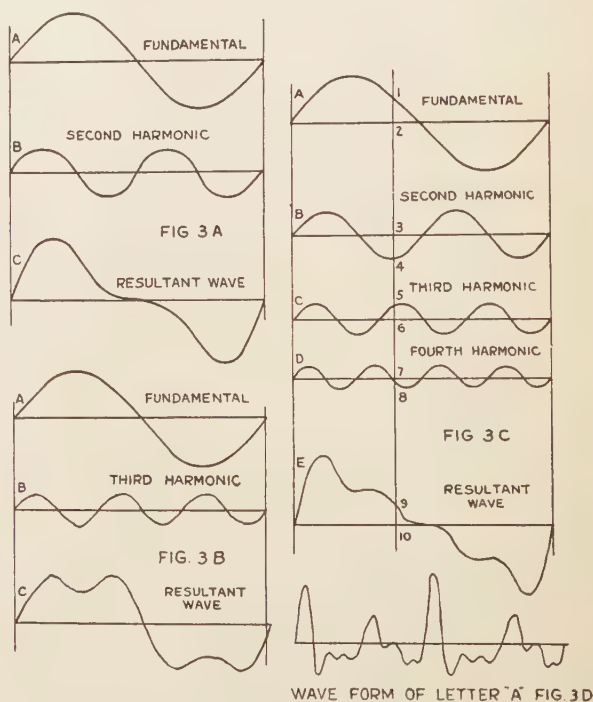


Fig. 3—Diagrammatic Representation of Waves and Harmonics

8. **SOUND SENSATION:** The sensation of sound as relayed to the human brain by the auditory nerve presents an interesting and important study. Two sounds, which have the same physical amplitude but which differ in frequency, do not sound equally loud. It requires a much greater amplitude in low than in high tones to produce equal loudness sensation. Notice the difference

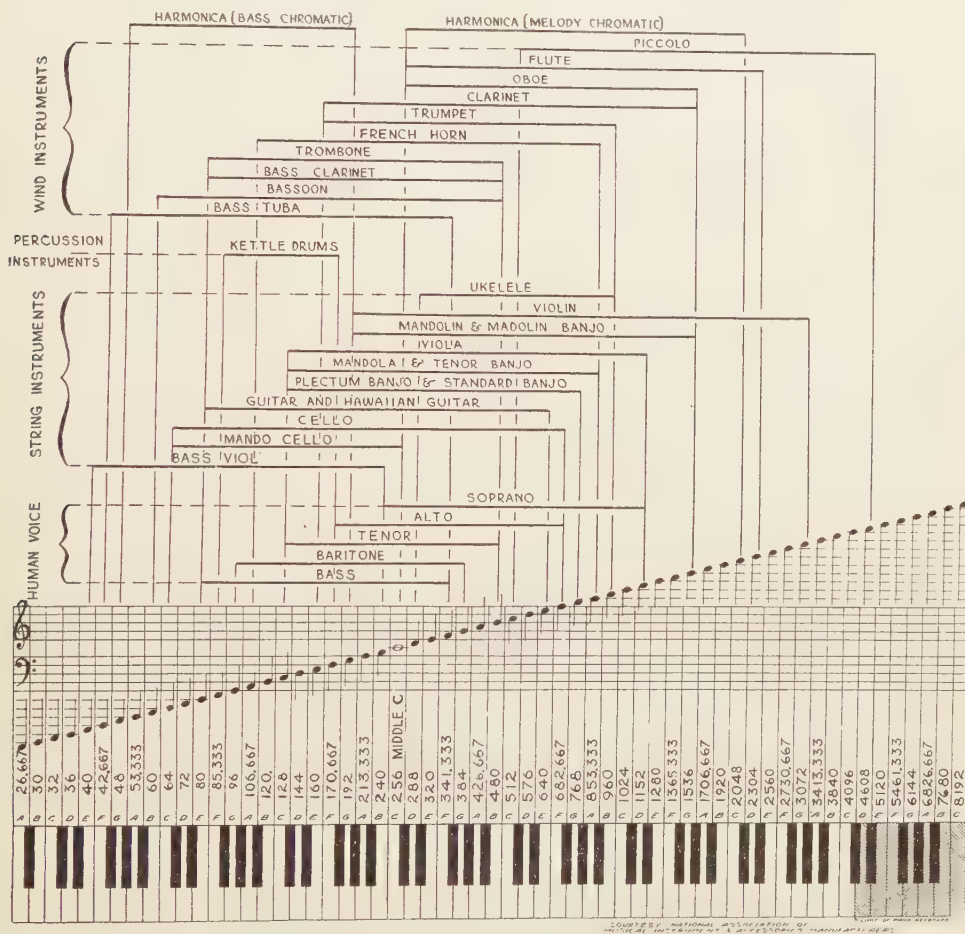


Fig. 4

in amplitude of vibration between one of the high note strings of a piano and one of the low note strings, even though the sound from the two is equally loud.

The energy of the vibration is proportional to the square of the frequency, the amplitude remaining constant. That is, if we had three sounds having equal amplitudes but frequencies of 20, 40 and 60 cycles respectively, the physical

energies would be in the ratio of 1, 4, and 9. However, these energy ratios do not exactly represent the loudness of the sounds as they would be heard by the ear because, for equal energies, the human ear hears sounds of very high frequency louder than those of very low frequency, and sounds of mid or normal frequency better than either. Thus it is evident that a loud speaker emitting low sounds from an organ selection is really handling a much greater amount of energy than when emitting the higher notes of a violin selection, even though the two sound equally loud.

Fig. 4 shows the keyboard of a modern piano together with the frequencies of the various keys and the frequency ranges of the various musical instruments. The lowest note on the keyboard has 27 vibrations per second, and the highest has 4,096, on the physical scale. Middle C represents a frequency of 256 cycles. The lowest C has 32 cycles. The C above this is an octave of it, and has a frequency of 64 cycles. The octave of a frequency is a frequency twice as large. For instance, low C has a frequency of 32, the second octave a frequency of 64, the third octave 128, the fourth octave, middle C, 256, the fifth octave 512, and so on.

The practical range of frequencies, with the attendant important harmonics, employed in the playing of a selection on a piano ranges from about 32 to 6,000 cycles per second. This allows for the lower and higher keys, which are seldom used. This is approximately the range of sound frequencies which are broadcast over the radio. Among the various familiar musical instruments the bass violin goes down to the lowest frequency of 40 cycles and the piccolo and piano employ frequencies as high as 4,096 cycles.

The shaded keys in Fig. 4 are not included on the standard piano keyboard.

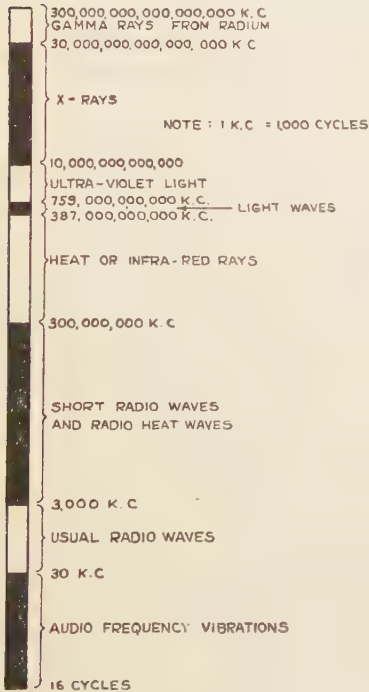
9. RADIO, HEAT AND LIGHT WAVES: If we heat a piece of iron or steel, such as a hack saw blade, in a gas flame, it gets hot. Continuing the heating causes the blade to change color, first turning to a dull red, then a bright "cherry red," to slightly orange and finally it gets "white hot." In this simple experiment a series of waves of different frequencies are produced, giving rise to the different effects noted. When heat is applied to the blade it sets the molecules of the iron into vibration, producing heat waves which are radiated in all directions. As more heat is applied, the molecules vibrate faster and faster causing the radiated waves to follow one another more closely, i.e., the frequency is increased and the wavelength decreased.

These waves, coming off at higher and higher frequency, produce the sensation of light of changing color, ranging from dull red for the lowest frequency, to cherry red, orange and, finally, bright yellow at the highest frequency. Just as the pitch of a sound is determined by the frequency of vibration of the body which produced it, so the color of light is determined by the frequency of the vibration producing it. The color red is produced by vibrations of lower frequency than those of the color yellow. Other colors are produced by vibrations whose frequencies are between and above these extremes in the order red, orange, yellow, green, blue, violet.

Thus far we have discussed sound waves produced by mechanical vibration of the air, having frequencies between 16 and 20,000 cycles per second and

in our experiment we produced heat waves and light waves. These three types form only a small portion of all the classes of waves known to science today. The entire series is divided into bands for convenience. Starting with low frequencies we have the sound waves consisting of simple mechanical vibrations between 16 and 20,000 cycles per second. Above these we have the waves employed in radio, ranging from 20,000 to 3,000,000 cycles per second. Then come the short radio waves and radio heat waves recently discovered by Dr. E. H. Nichols, comprising a range from 3,000,000 cycles to 300,000,000,000 cycles. Above these lie the heat waves, then the ordinary light waves, and ultra-violet

light waves or rays. These latter rays are given off by X-ray tubes, the sun, and the electric arc.) Following these we have the X-rays and then the Gamma rays, which are the shortest known at the present time. Above these is an unexplored region of waves still shorter than the Gamma rays. The wave series is shown in Fig. 5, with the approximate frequency limits for each band. The divisions of radio, heat, light and ultra-violet light waves are made merely for convenience. They really all belong to one series; they are all electromagnetic waves which travel through space at the rate of 300,000,000 meters or 186,000 miles per second, and differ from each other physically only in the frequency of their vibration or wavelength. These electric waves are of an entirely different nature than sound waves, since sound waves are not electrical and consist of actual to-and-fro motions of the air particles. The speed of the electric waves is so great that they can be considered to move between any two points practically instantaneously. The difference in frequency gives the various kinds of electric waves the properties which are peculiar to them. Thus, radio waves travel with perfect ease through practically all substances, while light and heat waves travel only through certain substances.



WAVE SERIES FIG 5

Just exactly what these radio waves are, and how they travel we do not know—any more than we know what electricity is. But just as with the case of electricity, we know how they behave under various conditions, and we are finding out more and more about how to control them for our own use. The question of how they travel is being investigated by many of our most brilliant scientific men and, it is safe to say, the time is not far off when we will know as much about the behavior of radio waves as we do now about simple electric currents. It is these radio waves which make modern radio broadcasting possible, and their production and use in the broadcasting station will be treated in a later chapter.

REVIEW QUESTIONS.

1. Why are radio waves used to transmit sound programs in radio broadcasting?
2. Draw a diagram of a simple radio broadcasting system.
3. Define cycle, frequency, wavelength.
4. Of what importance are "harmonics" in music?
5. What is an octave? What is the octave of middle "c"?
6. Which musical instruments reproduce the low frequencies, the middle frequencies, the high frequencies?
7. What range of frequencies is covered in ordinary music?
8. What range of frequencies is covered by the various singing voices?
9. Why does middle "C" sounded in a piano sound differently than middle "C" sounded on a violin?
10. What is the physical difference between X-ray waves, radio waves, ultra violet light waves, heat waves, etc.? What feature do all of these waves have in common?

CHAPTER 2.

CURRENT, MAGNETISM, AND SIMPLE ELECTRIC CIRCUITS.

ELECTRIC CIRCUITS — ELECTRIC THEORY — VOLTAGE — CURRENT — RESISTANCE — OHM'S LAW — SERIES CIRCUITS — PARALLEL CIRCUITS — SERIES-PARALLEL CIRCUITS — RHEOSTATS — KINDS OF CURRENT — ALTERNATING CURRENT — MAGNETISM — MAGNETIC EFFECT OF CURRENTS — ELECTROMAGNETIC INDUCTION — INDUCTANCE — CAPACITY — INDUCTIVE REACTANCE — CAPACITIVE REACTANCE — IMPEDANCE — RESONANCE.

10. **ELECTRIC CIRCUITS:** The study of radio broadcasting necessarily includes a thorough understanding of the action of electric currents and circuits, since the transmitting and receiving stations deal entirely with electricity. While it is, of course, impossible to present a complete electrical course here, an attempt will be made to give enough of the fundamentals to enable the average person to grasp the material in the succeeding chapters and to act as a review for others.

The flow of electricity through a wire is always a puzzling thing to the novice, possibly because the action is not directly visible to the naked eye. We really do not know what electricity is, any more than we know what gravity or magnetism is. But like many other things, we can learn to use it and control it by studying its various peculiarities. Many theories have been advanced by prominent scientists to explain the reasons for the observed behavior of electric currents. The one most commonly accepted at present is the electron theory.

11. **ELECTRON THEORY:** It is generally known that all matter, such as the paper upon which this is printed, consists of small particles called molecules. These molecules may be further subdivided into what we call atoms. Thus a grain of ordinary table salt may be considered as consisting of many tiny particles, molecules of salt held together by some force of attraction. These molecules cannot be divided into smaller molecules of salt, but each one can be divided into atoms of different chemical substances. One molecule of salt can be split up into an atom of sodium and one of chlorine. Each atom in turn is believed to be made up of a center nucleus having a positive charge of electricity, around which revolves a number of small negative charges called electrons, Fig. 36. Under normal conditions, the positive charge of the nucleus is equal to the total sum of the negative charges around it, so that a state of balance exists. Atoms of different substances differ merely in the number of negative electrons surrounding the nucleus.

At least one of these electrons is "loose" or free to circulate around among its neighbors. When an electric current flows, what really happens is that these

free electrons move along the length of the wire, the movement giving rise to the various external effects which we associate with an electric current. Thus an electric current is merely a stream of free electrons passing through a conductor in the opposite direction which we usually ascribe to the electric current. Substances in which the loose electrons move around easily are called good conductors. Among these are gold, silver, copper, brass, iron, etc. Substances in which there are no free electrons, or very few, are called insulators. These include Bakelite, porcelain, mica, dry air, etc.

12. **VOLTAGE:** We have seen that the movement of electrons along a conductor constitutes an electric current. However, if we take a piece of copper wire and hold it in our hands, no electric current flows, since there is no force or tendency to make the electrons move. We must apply some external force (called voltage) to the wire, to produce the current. If we take a strip of copper wire and one of zinc, partly immersed in a solution of dilute sulphuric acid, and connect them with a wire (*AB*, Fig. 6), chemical action will take place and electrons will be removed from the copper and given to the zinc. This results in the copper plate having less than its normal number of electrons and the zinc plate having more than its number. The result is an unbalancing of the charges, and electrons will flow from *B* through the wire to *A* tending to equalize the charges again. This constitutes the flow of an electric current and we say the current flows through the wire from *A* to *B*. We have here a simple electric battery and *A* is the positive terminal and *B* is the negative terminal. The battery serves the purpose of causing a continuous flow as long as chemical action continues at the zinc, that is, as long as a voltage is present.

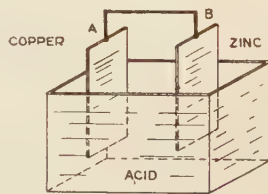


Fig. 6—The Elements of an Electric Battery

13. **CURRENT:** An electric current consists of a flow of electrons. If we measure the number of electrons flowing past a given point in a circuit in a unit of time (one second) we have a measure of the current. The unit of current measurement is the ampere. Current is usually measured by means of an instrument called an ammeter.

It must be remembered that a current of electricity cannot flow in a conductor unless there is some force or potential applied to it, just as no water can flow in a pipe unless there is some pressure applied.

14. **RESISTANCE:** When current flows through a conductor it encounters opposition or resistance, just as water flowing through a pipe encounters resistance due to friction between it and the walls of the pipe. The resistance to current flow depends on the material of which the conductor is made. Silver has the least resistance, annealed copper is next lowest, etc. The resistance also depends on the length, a conductor three feet long having three times the resistance of one that is one foot long, other things being equal.

Resistance is also inversely proportional to the cross-sectional area of the conductor. Conductors of large diameter have less resistance than conductors

of small diameter. The resistance of most conductors also increases as the temperature is increased.

15. **OHM'S LAW:** We have now considered the three fundamental things about electric currents: first, the flow of electrons, constituting an electric current; second, the potential or force which causes the current's flow; third, the resistance or natural opposition which every conductor offers to the flow of current through it. There is a fundamental relationship between these three factors, known as Ohm's Law.

If current in amperes is denoted by I , potential or pressure by E , and resistance by the letter R , then Ohm's Law states that the current in amperes is equal to the potential in volts divided by the resistance in ohms; that is

$$I = \frac{E}{R} \dots\dots\dots (2)$$

In order to fix this relation more clearly in mind, let us consider a few examples dealing with electric circuits. (a) The filament of a vacuum tube has a resistance of 24 ohms. What current will flow through it when connected across a 6-volt storage battery?

$$\text{Ans. } I = \frac{E}{R} = \frac{6}{24} = 0.25 \text{ ampere.}$$

(b) What potential must be applied across a resistance of 24 ohms in order to send a current of 0.25 amperes through it?

$$\text{Ans. } I = \frac{E}{R} \text{ or } E = I \times R$$

$$\text{Therefore } E = 0.25 \times 24 = 6 \text{ volts.}$$

(c) A 6-volt storage battery is connected across a resistance and the current flowing is found to be 0.25 amperes. What is the value of resistance?

$$\text{Ans. } I = \frac{E}{R} \text{ or } R = \frac{E}{I}$$

$$\text{Therefore } R = \frac{6}{0.25} = 24 \text{ ohms}$$

From these examples it will be seen that if any two of the above expressions, either potential, resistance or current, are known, the remaining one can be found by applying Ohm's Law.

One million ohms is called a "megohm." Thus 0.5 megohm is equal to 500,000 ohms; 100,000 ohms equals 0.1 megohm, etc.

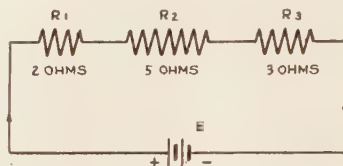
16. **SERIES CIRCUITS:** In order for current to flow in any conductor, the circuit must be complete. In actual electrical circuits, parts are connected in either of two ways—or a combination of the two. When they are connected in such a way that the total current of the circuit flows through all of them, they are

said to be in series. If two or more resistances are connected in series (as in Fig. 7) the total resistance is equal to the sum of the separate resistances.

In Fig. 7 the total resistance is: $R=R_1+R_2+R_3 \dots\dots\dots (3)$

If $R_1=2$ ohms, $R_2=5$ ohms, $R_3=3$ ohms, and $E=20$ volts, then the total resistance is $R=2+5+3=10$ ohms, and the current flowing in the circuit is:

$$I = \frac{E}{R} = \frac{20}{10} = 2 \text{ amperes.}$$



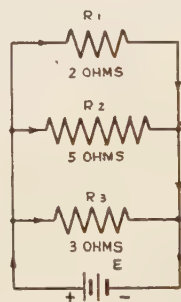
SERIES CIRCUIT FIG. 7

17. PARALLEL CIRCUITS: When parts of a circuit are connected so that the total current is divided between them, as in Fig. 8, they are said to be in parallel with each other. When resistances are connected in parallel the total resistance (R) is expressed by the formula:

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \dots\dots\dots (4)$$

Taking the same values of resistances as is the previous example, the total resistance R of the three resistances connected in parallel is:

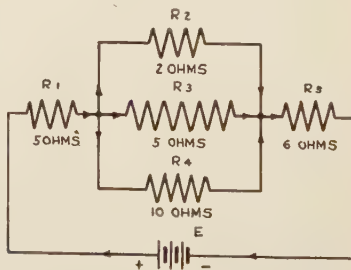
$$R = \frac{1}{\frac{1}{2} + \frac{1}{5} + \frac{1}{3}} = 0.99 \text{ ohms.}$$



PARALLEL CIRCUIT FIG. 8

From this it can be seen that connecting the resistances in parallel lowers the total resistance, since more paths are provided for the current flow.

18. SERIES—PARALLEL CIRCUITS: If the parts of the circuits are connected up so that some of them are in series and some are in parallel with each other, then the total resistance can be found most easily by reducing the entire circuit to an equivalent series or parallel circuit, depending upon the combination. Thus, in Fig. 9 we have R_2 , R_3 and R_4 connected in parallel, and this combination in series with R_1 and R_5 is connected across the 6-volt battery. To find the total resistance of the circuit first find the total resistance of R_2 , R_3



SERIES PARALLEL CIRCUIT FIG. 9

and R_4 , and then consider the circuit as consisting of this resistance connected in series with R_1 and R_5 .

Let $R_1=5$ ohms, $R_2=2$ ohms, $R_3=5$ ohms, $R_4=10$ ohms, $R_5=6$ ohms.

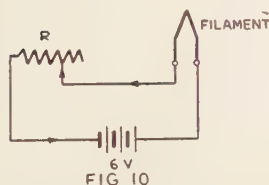
The total resistance of R_2 , R_3 , and R_4 is then

$$R = \frac{1}{\frac{1}{2} + \frac{1}{5} + \frac{1}{10}} = 1.25 \text{ ohms.}$$

The total resistance of the complete circuit is:
 $R=1.25+R_1+R_5=1.25+5+6=12.25$ ohms.

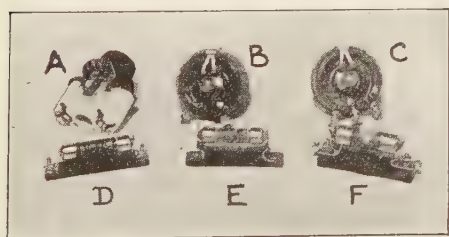
The total current flowing through the circuit is

$$I = \frac{E}{R} = \frac{6}{12.25} = 0.49 \text{ ampere.}$$



**Filament in Series
With Rheostat**

19. RHEOSTATS: As stated previously, resistance in a circuit opposes the flow of electric current. There is a certain amount of resistance in every electric circuit due to the connecting wires, etc. In some cases extra resistance is added intentionally to reduce the current flowing. An example of this is seen in the use of rheostats, adjustable resistances, in the filament circuits of ordinary vacuum tubes used in radio receiving sets. Here the current from a storage battery flows through the filament of the tube and heats it to incandescence. The amount of current flowing is regulated by connecting a variable resistance R in



**Fig. 11—Several Forms of Resistors
Used in Radio Sets**

series with the filament, Fig. 10. Resistances are made in a variety of forms, depending upon their particular use. Low resistances for radio work are usually made of wire wound on some suitable insulating material. Very high resistances of several thousand ohms or more are made either of paper impregnated, or coated, with some carbon particles, or consist of a glass thread coated with a very thin layer of metal. Other adjustable high resistances make use of

carbon or graphite discs or powder which may be pressed together tightly to decrease resistance, or allowed to separate to increase resistance. Several popular forms of resistors used in radio receivers are shown in Fig. 11. "A" is a variable high resistance containing graphite powder; "B" is a wire wound medium resistance rheostat used for controlling the filament current of vacuum tubes; "C" is a wire wound high resistance potentiometer; "D," "E" and "F" are ballast resistors used to maintain a constant filament current. They consist of pieces of special wire enclosed in an airtight glass tube with metal connecting caps at the end.

A clear mental picture of resistance may perhaps be obtained by the following consideration. If we take a piece of wire of any definite diameter, length and material, it has a certain value of resistance. If we make the wire twice as long,

its resistance will be twice as much. If we decrease its length the resistance will be decreased. Now if we keep its length constant but increase the diameter, or cross-sectional area, the resistance will decrease; if we decrease the diameter, resistance increases.

20. **KINDS OF CURRENT:** Fundamentally, electricity itself is always the same in any circuit no matter whether it is produced by chemical action in a battery, by a generator, or any other way. Electricity, as we deal with it in our lives, however, is usually in the form of one of three types of electric currents. When the current flows in but one direction through a circuit it is known as direct current, commonly abbreviated D.C. This is the kind of current supplied by all forms of batteries, and flows from the positive terminal of the battery, through the circuit, to the negative terminal. If the current flows in one direction, but is pulsating, that is, increases and decreases in strength, it is known as pulsating current. If the current not only varies in strength but also changes its direction of flow many times a second it is called an alternating current, commonly abbreviated A.C. This difference in the way in which the current flows through a conductor gives rise to various effects which will be studied later.

21. **ALTERNATING CURRENT:** It is perhaps difficult for the non-technical person to grasp the idea of the flow of alternating current along a wire, but possibly a simple explanation may make this clear. Let us consider a fixed point in a wire carrying an alternating current. Starting at some instant when current just begins to flow, let us observe its strength and direction over a short period of time. The current begins to flow in one direction, gradually increasing in strength to a maximum value, then still flowing in the same direction, it decreases again to zero. It now reverses once more and the cycle is completed over and over again. A chart showing the cycle of events is given in Fig. 12. Here the flow of current in one direction is drawn above the zero line $A C E$, and the polarity indicated positive by the plus (+) sign, and the flow in the opposite direction is drawn below this line and the polarity indicated negative by the minus (-) sign. The current starting at A rises to a maximum positive (+) value B in one direction and increases to a maximum negative (-) value D , and back to zero at E . The next cycle is a duplicate of this. The reader will notice the similarity between this curve and those discussed in Chapter I. From A to C is termed an alternation, from A to E is one cycle. The number of complete cycles or reversals of current per second is called the "frequency," expressed by the symbol " f ." This term frequency is very important, since it determines the many peculiar effects produced in alternating current circuits.

Alternating current used for electric lights in the home generally has a frequency of 60 cycles, that is, it incorporates 60 positive (+) values and negative

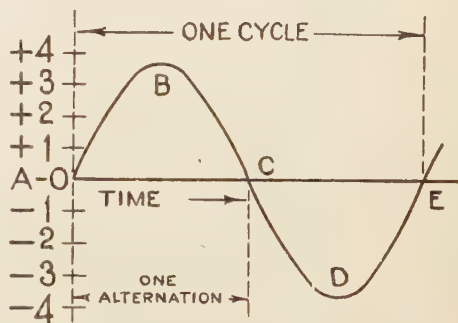


Fig. 12—Graphical Picture of One Cycle of Alternating Current

(—) values each second or a total number of reversals or alternations of 120, or two times the frequency per second. Alternating currents used in radio vary all the way from 16 cycles to 30,000,000 cycles per second and more. High frequency currents have many peculiarities totally different from those of the same currents at lower frequencies. For instance, if we take a coil consisting of a few hundred turns of insulated copper wire, we can send a low frequency alternating current through it very readily. If the voltage applied is kept constant and the frequency is increased, the current flowing through the coil decreases, or, in other words, the "resistance" of the current path increases. If the frequency is raised to a very high value, the current seemingly no longer flows through the wire of the coil, but apparently flows across the surface from one turn to the next through the insulation and air space between turns. These phenomena will be studied in more detail in a later chapter.

22. **MAGNETISM:** The reader is perhaps familiar with the common horse-shoe magnet used in boyhood days to pick up nails and needles. In ancient days, it was found that certain stones, called "lodestones", had the property of attracting small pieces of iron. This property of attracting iron and steel is called "magnetism", and the body possessing it is called a magnet. Later it was found that these stones had the property of imparting magnetism to other pieces of iron or steel when they were rubbed together. We do not know just what magnetism is, but it makes itself evident as an attractive force affecting only certain materials and acting along certain definite lines of direction. The ends of a magnet, where the forces of attraction or repulsion are greatest, are called the magnetic poles. Actually there are no visible lines of force existing around a magnet, but the study of magnetism is very much simplified by representing these magnetic forces by lines extending from one pole through space and to the other pole and having the same indicated direction at every point, as the forces themselves. The lines of force are assumed to come out of one pole, called the north pole (N), and pass through the surrounding medium back to the other pole, called the south pole (S), where they enter the magnet and return to the north pole, thus completing the magnetic circuit. The space adjacent to the magnet enclosing these lines of force is termed the "magnetic field". Every magnetic line of force must enclose a complete circuit, so it is impossible to have a magnet with only one pole.

23. **MAGNETIC EFFECT OF CURRENTS:** Whenever an electric current flows through a conductor magnetism is produced. The fact that a conductor, carrying a current, possesses an external magnetic field can be proven by bringing a small compass needle near the wire and noting its deflection. The magnetic field around a straight wire carrying a current consists of circular magnetic lines of force having the axis of the wire as their center. These circles are very close together near the wire and gradually thin out as the distance from the wire increases. Fig. 13 (A) shows the circular magnetic fields around a wire in which the current from a battery is flowing in the direction shown by the arrows.

If the direction of the current in a straight wire is known, the direction of the circular magnetic field around it can be determined by the Right-Hand Rule: grasping the wire with the fingers of the right hand, with the thumb extended in the direction of current flow, the direction in which the fingers are pointed will indicate the direction of the magnetic lines of force. This is graphically shown in Fig. 13 (B), which shows a length of wire through which current is flowing

in a direction indicated by the arrow, or from the left toward the right of the illustration. The circular magnetic fields are shown having a direction as indicated by the arrows, which is also the direction indicated by the pointing of the finger tips.

If the long straight wire is wound into the form of a coil as shown in Fig. 13 (C), several things happen to the magnetic field. Remembering that the circular magnetic fields exist all along the length of the wire of the coil, it is evident that the fields existing around the adjacent turns of the wire will react upon each other. The parts of the circular magnetic fields of each turn which lie inside the coil are in the same direction as those of every other turn. The result is that they aid each other to produce a strong total magnetic field inside the coil winding, and the magnetic lines of force become straight to within a short distance of the ends of the coil. On the outside of the coil, the same action takes place, with the result that the magnetic field of the coil takes the form shown by the lines in Fig. 13(D). The magnetic lines are close together inside the coil, producing a dense field there, while at the poles they spread out, creating a weaker field in the medium surrounding the coil. If you look at one end of the coil, and the current is flowing around in the same direction that the hands of a clock move, or to the right, then the end of the coil nearest you is the south magnetic pole. If the current flows in a counter-clockwise direction, or left-hand direction, then the end of the coil nearest you is the north magnetic pole of the coil.

24. ELECTROMAGNETIC INDUCTION: In the previous paragraph it was stated that a current flowing through a conductor produces a magnetic field, in the medium surrounding that conductor. If a wire forming a closed circuit is moved across a magnetic field or if the magnetic field is moved across the wire, so as to cut the magnetic lines of force (the effect is a maximum when the moving wire or field is at right angles), a current of electricity is induced in the closed circuit. In both cases the strength of the induced current depends upon the following factors:

1. The strength of the magnetic field.
2. The speed at which the lines of force are being cut.
3. The number of wires cutting the lines of force per second.

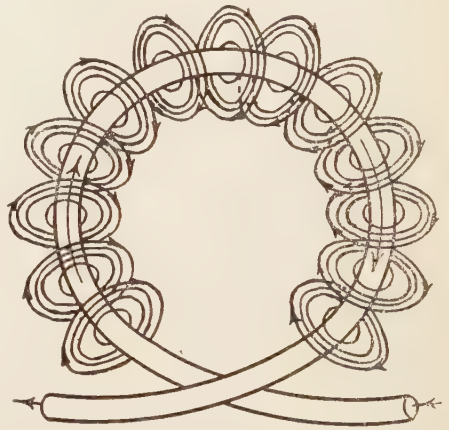


Fig. 13A—Magnetic Lines of Force Existing Around a Conductor Carrying An Electric Current

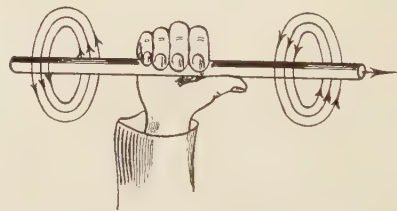


Fig. 13B—Illustrating the "Right Hand Rule"

25. INDUCTANCE: The electromagnetic field produced by a current flowing through a wire varies with the current. When a steady direct current is sent through a wire, a steady electromagnetic field is produced, and no current is induced in either the conductor itself or in an adjacent conductor.

When an alternating current flows through a wire, since it changes its direction once every alternation, or twice every cycle, the electromagnetic field produced by it does likewise, and since the current varies in strength, of course the induced current also varies. When the current begins to flow along the wire, the circular electromagnetic fields, originating at the electrical center of the wire, travel away from the center in ever-increasing diameters, and, of course, extend into space beyond the wire. Consequently, until the circular fields become of greater diameter than the wire itself, the fields, by the action explained in Section 24, induce in that same wire a second current. It can be proved that this induced current is in a direction opposite to the main current and therefore opposes it.

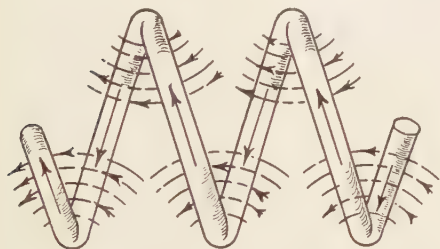


Fig. 13C—Magnetic Fields Existing Around the Individual Turns of a Coil of Wire

When the current flowing through the wire decreases or stops flowing, the circular electromagnetic fields collapse and in so doing again cut the wire, but in succeeding ever diminishing diameters, inducing in it a current in the opposite direction, which is in the same direction as the original applied current. Consequently, this induced current tends to prolong, or prevent, the main current from flowing. This property of a wire or coil to act inductively upon itself or upon another circuit is called "inductance", and the unit of measurement of inductance

is called the "henry," expressed by the symbol L . It is the inductance of a circuit in which the induced e. m. f. is one volt when the current varies at the rate of one ampere in one second.

In some branches of radio work, particularly in radio frequency circuits, the inductances are so small that their sizes are expressed in units smaller than the henry. Thus, one one-thousandth of a henry is a "millihenry," one one-millionth of a henry is a "microhenry," etc.

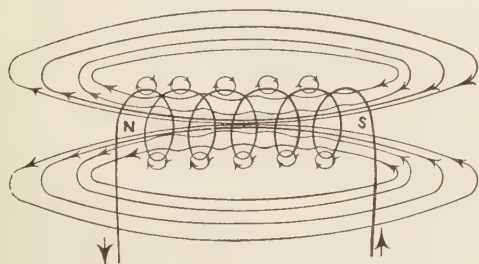


Fig. 13D—The Total Magnetic Field of an Inductance Coil

The amount of inductance possessed by a circuit depends upon its physical form and dimensions. Thus, a single straight wire has a comparatively low inductance. The same wire, however, when wound into a coil of many turns, has a high inductance. Inductance in a circuit opposes the flow of alternating current.

26. CAPACITY: If two metal plates are insulated from each other with some material such as waxed paper, or air, they form an electrical condenser or

capacitance; that is, a device capable of containing a quantity of electric charge. (See Chapt. XIV.)

If a voltage is applied to the two plates by means of a battery, a current will flow into the condenser until it is charged to the same voltage as that of the battery. If the battery is now removed and the two terminals of the condenser are touched together, a spark will be produced by the discharging current, flowing out of the condenser in the reverse direction to the charging current.

When a condenser is connected in an alternating current circuit it is charged to a voltage equal to the maximum applied voltage during the first quarter cycle, is discharged during the next quarter cycle, is charged again in the opposite direction during the third quarter cycle, and discharged again during the last quarter cycle (see Fig. 12). This is repeated over and over again during each cycle. Actually no current flows *through* the condenser itself since the alternate plates are insulated from each other, but the charge and discharge currents flowing in the external circuit would make

it appear as though a current was flowing through the condenser itself if a current indicating device were connected in series in the circuit. This is shown in Fig. 14. The unit of measurement of capacity is called the "farad," and is expressed by the symbol C. It is the capacity which under one volt pressure will take up enough electricity to maintain a

flow of one ampere of current for one second. In practice, this is an enormous capacity. A condenser of one one-millionth of this capacity is a good-sized one. We call one one-millionth of a farad a "microfarad"; the word is abbreviated mf. or sometimes mfd. Condensers used in the filter circuits of electric receivers may be of from 1 to 10 mfd. capacity, while those used in the radio frequency tuning circuits of radio receivers are usually in the neighborhood of 0.00035 mfd. capacity. These very small capacities are very conveniently measured by the micro-microfarad, abbreviated mmf. or sometimes mmfd. One microfarad is 1,000,000 mmfd.; as .001 mfd. is 1,000 mmfd., so .0005 mfd. is 500 mmfd. and .00035 mfd. is 350 mmfd., etc.

27. INDUCTIVE REACTANCE: From the previous explanation, it is evident that inductance tends to oppose the flow of the current in an alternating current. This opposition effect may be considered as an apparent resistance additional to the natural or direct-current (zero frequency) resistance of the circuit. The total effect is called "inductive reactance", and is expressed by the symbol X_L to distinguish it from the direct current resistance R . Since inductive reactance causes an opposition to the flow of the current, it is expressed in ohms, like resistance. In a circuit containing inductance only, the current lags 90 degrees behind the applied voltage. The value of the inductive reactance X_L in ohms depends upon both the frequency of the voltage and the inductance of the circuit. It may be expressed by the formula:

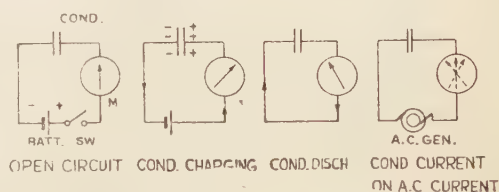


Fig. 14—The Charge and Discharge of a Condenser in an Electric Circuit

$$X_L = 2 \times 3.1416 \times f \times L \dots\dots\dots (5)$$

where f = the frequency in cycles per second

L = the inductance in henrys

X_L = inductive reactance in ohms.

28. **CAPACITIVE REACTANCE:** The strength of the charge and discharge currents in a condenser depends on the capacitance C of the condenser, the applied voltage E , and the frequency f . Thus the condenser may be considered as a part of the circuit, having an apparent resistance in ohms, called its "capacitive reactance" and represented by the symbol X_C .

In a circuit containing only capacitance (commonly called "capacity") the current leads the applied voltage by 90 degrees. The capacitive reactance is equal to:

$$X_C = \frac{1}{2 \times 3.1416 \times f \times C} \dots\dots\dots (6)$$

where f = the frequency in cycles per second

C = the capacitance in farads

X_C = the capacitive reactance in ohms.

From this formula it can be seen that as either the frequency or the capacitance, or both, is increased, the resistance or reactance which a condenser offers to the flow of alternating current decreases. This is exactly opposite to the effect of inductance in a circuit.

39. **IMPEDANCE:** Thus far we have considered alternating current circuits which contain only inductance or capacitance. The circuits met with in practice always have resistance as well as inductance or capacitance, and in some cases circuits contain resistance, inductance and capacitance. When a circuit contains both inductance and capacitance, the net reactance X is equal to the arithmetical difference between the inductive reactance X_L and the capacitive reactance X_C , or $X = X_L - X_C$. This is because the effects of the inductance are exactly opposite to those of the capacity.

The combined opposition to current flow offered by the resistance, inductance and capacitance of a circuit is called the "impedance." It is represented by the symbol Z and is expressed in ohms.

The impedance of a circuit containing resistance R , inductance L and capacitance C is

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \dots\dots\dots (7)$$

or substituting in equation (7) the values of X_L and X_C from equations 5 and 6 we get

$$Z = \sqrt{R^2 + \left(2 \times 3.1416 \times f \times L - \frac{1}{2 \times 3.1416 \times f \times C} \right)^2} \dots\dots\dots (8)$$

In dealing with alternating currents, Ohm's law must be modified slightly. The current I in any circuit is equal to the voltage E applied to the circuit divided by the impedance (or total opposition to current flow) Z , of the circuit.

$$\text{or } I = \frac{E}{Z}$$

$$R^2 + \sqrt{\frac{E}{\left(2 \times 3.1416 \times f \times L - \frac{1}{2 \times 3.1416 \times f \times C}\right)^2}} \dots\dots\dots (9)$$

30. **RESONANCE:** From formula 9, it can be seen that if we have an alternating current circuit to which a definite voltage E is applied, a maximum current I will flow when the impedance Z is made as small as possible. Now let us examine formula 9. In order to make Z as small as possible, we must reduce the resistance R to zero and make the inductive reactance X_L equal to the capacitive reactance X_C so that

$$X_L - X_C = 0 \dots\dots\dots (10)$$

It is quite impossible to make R equal to zero, since all conductors have some resistance; but for any given frequency f , we can choose the inductance and capacity so that the inductive reactance X_L is equal to the capacitive reactance X_C , so that

$$2 \times 3.1416 \times f \times L = \frac{1}{2 \times 3.1416 \times f \times C}$$

then in such a circuit

$$Z = \sqrt{(R)^2 + (0)^2} = \sqrt{R^2}$$

therefore $Z = R$.

The circuit then operates as though there were neither inductance nor capacity present, and it is said to be in "resonance" with the impressed alternating frequency.

This resonance effect is applied in practically all of our present radio receiving circuits today where the minute voltages set up in the aerial circuit are made to produce the largest currents possible in the tuned circuits. The usual circuit to obtain resonance is one having a variable condenser connected in series with a fixed inductance. By varying the capacity of the variable condenser the circuit can be brought to resonance for currents of any frequency within the range of the particular coil-condenser combination used. This will be studied in more detail in connection with the design of tuning coils.

REVIEW QUESTIONS.

1. State the electron theory briefly.
2. What makes current flow in a conductor?
3. What three factors does the resistance of a conductor depend upon?
4. State Ohm's law. Write the formula for it.
5. What is the combined resistance of three resistors, 5, 10 and 15 ohms, in series?
6. What is the combined resistance of three resistances, 5, 10 and 15 ohms, in parallel?
7. What is the combined resistance of 5, 10 and 15 ohm resistances connected all in series, when connected in series with 10 and 15 ohm resistances connected in parallel with each other?
8. Describe the construction of some rheostats used in radio work.
9. Define direct current, alternating current, pulsating direct current.
10. Upon what three factors does the strength of the induced current in electromagnetic induction depend?
11. What is meant by inductance, capacity, inductive reactance, capacitive reactance, impedance, resonance?
12. How is the effect of resonance applied practically in radio receivers?

CHAPTER 3.

THE BROADCASTING STATION, TRANSMISSION

BROADCASTING — MICROPHONE — TRANSMISSION — WAVE TRANSMISSION — MODULATION—RADIATION—THE BROADCAST STATION—REMOTE CONTROL—WAVE PROPAGATION—FADING—HEAVISIDE LAYER—SKIPPING.

31. **BROADCASTING:** In Chapter I it was stated that instead of transmitting sound waves directly, as in the case of one person talking to another across a room, a radio telephone transmitter converts them into corresponding electrical waves. The sound waves vary in intensity and form due to the presence of harmonics. The human voice includes a range of from about 200 to 3,000 cycles per second and the average frequency during ordinary speech is about 800 cycles per second.

The first step in broadcasting is to change the air or sound waves into corresponding electric currents, or more exactly speaking, to make the waves control an electric current. This is accomplished by the microphone.

32. **THE MICROPHONE:** The most popular form of microphone is the carbon type. Its operation is similar to that of the common telephone transmitter.

Fig. 15 shows a cross sectional view of a simplified microphone. The diaphragm "A," of thin aluminum or iron is rigidly fastened to the polished carbon button "B" and is held fixed around its outside edge by the insulated case "E." A second carbon button "D" is fastened rigidly in place and the space between them is filled with tiny carbon granules "C." A connection is taken from each of the carbon buttons, so that current must flow from one button through the carbon granules to the other one. The air waves created by the performer in the broadcast studio strike against the diaphragm and cause it to vibrate back and forth very rapidly, following the sound wave motion. This also vibrates the button "B," causing alternate pressures and rarefactions in the carbon granules. The resistance of these granules varies greatly as the pressure upon them is changed, being very high during a rarefaction, when the particles are

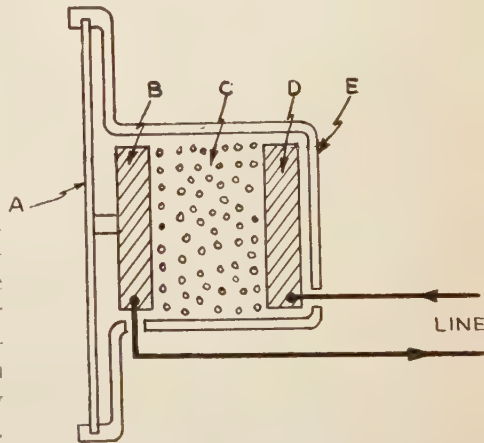


Fig. 15—Simple Carbon Type Microphone

held loosely, and comparatively low during a pressure, when they are packed tightly. Thus the movement of the diaphragm alters the resistance of the microphone and so varies the current flowing through it in exact accordance with sound waves.

Fig. 16A shows the steady direct current flowing through the microphone when the diaphragm is undisturbed, and the variation in current produced by transmitting the sound of "a" as in "father" is shown in Fig. 16B. It is evident that the microphone acts merely as a variable resistance in the circuit.

Fig. 17 shows a common form of microphone used in most studios. This is the double button type, and is arranged to utilize both the forward and backward

movements of the diaphragm to produce better variation or modulation of the current. The mechanism is suspended by springs to prevent noises due to accidental jarring, and is enclosed in a housing.

Another form of microphone operates by the change in capacitance due to the movement of one diaphragm separated from another one by only a few thousandths of an inch. This is known as the condenser microphone. The galvanometer type operates by the movement of a coil of wire in a strong magnetic field. The coil moved in the field by the diaphragm has small currents set up in it which vary in strength corresponding with the movements of the diaphragm.

The microphone changes the sound waves or vibrations into corresponding variations in electric current. Since the audible range of vibrations extends from about 16 to 20,000 cycles per second, it is evident that the current in the microphone circuit must vary over this range during a broadcast program. The next problem is to transmit the varying current through space to the receiving station.

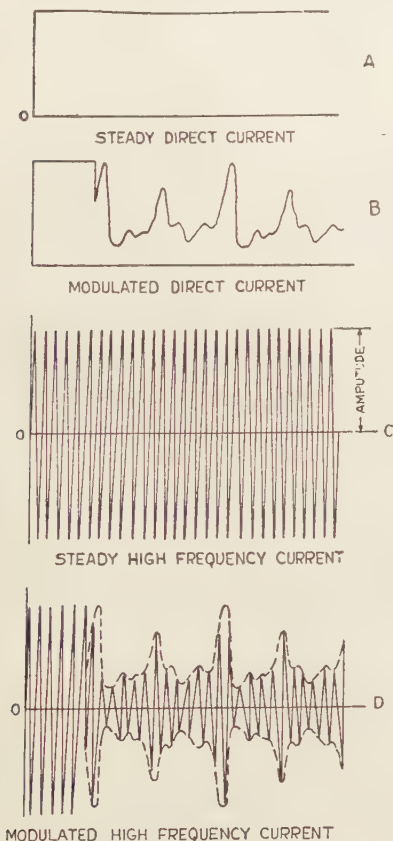


Fig. 16—Modulation of Direct, and High Frequency Alternating Current by Impressed Speech Frequencies

electromagnetic wave radiation into space. Fig. 18 shows a simple circuit for transmission by inductive effect.

If a direct current is sent through wire AB, a magnetic field will be set up around it as soon as the current starts to flow, and will collapse as soon as the current stops. If an alternating current is sent through it, there will be a constantly

33. TRANSMISSION:

The two ways in which energy can be transferred from the transmitting antenna to the receiving aerials are by electromagnetic induction effect and by electrostatic and

changing magnetic field, which is set up and collapses every time the current changes in direction. Since the strength of the magnetic field at any instant depends upon the strength of the current at that instant, the field strength grows to a maximum and then diminishes to zero, over and over again. If the conductor CD is located in this varying magnetic field, a current will be induced in it by the action of the field, and this current will be an exact duplicate of that flowing in AB. This action is called electromagnetic induction and is the principle upon which all transformers operate.

If AB is an antenna carrying alternating current and CD is a receiving aerial near it, then it is evident that the magnetic field around AB will induce currents in the receiving aerial. However, as the distance from antenna AB is increased, the strength of the magnetic field decreases very rapidly (inversely proportional to the square of the distance) until at a comparatively short distance, depending upon the strength of the current, its effects are negligible. It is evident then that this system of transmission by pure electromagnetic induction would be unsuitable for broadcasting, since enormous power would be necessary to transmit over any appreciable distance.

34. **WAVE TRANSMISSION:** In Fig. 19 the common open type transmitting circuit is shown. In this circuit the disturbance in space is caused primarily by electromagnetic fields which travel outward in all directions in the form of waves. Open circuits are much more effective radiators of electrical energy than closed ones, but even with an open circuit radiator enormous power would be necessary to send out waves having frequencies from 16 to 6,000 cycles per second (same as speech and music), over long distances. The radiation from any given circuit increases greatly as the frequency of the current in the circuit increases. This is one of the reasons why it is possible for amateurs transmitting at frequencies above 6,000,000 cycles per second (below 50 meters) to reach nearly around world employing powers of a few watts. It is due to these characteristics of transmission, then, that in order to transmit over long distance with the expenditure of a reasonable amount of power, the open circuit type antenna or radiator



Photo Courtesy Station WOR

Fig. 17—Microphone and Announcer

is used, and currents of very high frequencies, running into millions of cycles per second, are employed for broadcasting.

35. **MODULATION:** The practical way of transmitting radiophone programs by means of currents of very high frequency is to use a high frequency current which varies in strength according to the intensity and frequency of the

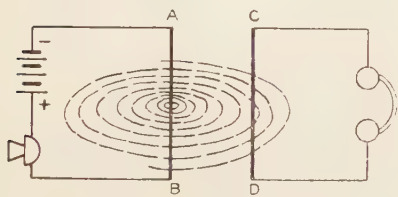


Fig. 18—Electrio-magnetic Induction



Fig. 19—Wave Forms of Energy Transmission by Electro-magnetic Wave Radiation

sound waves to be transmitted. A steady current of very high frequency, determined by the operating wavelength of the station, is generated by means of large vacuum tubes operated as oscillators. This is shown in Fig. 16C. Notice that it is an alternating current and that the height or strength of the current during each cycle is exactly the same as during any other cycle. The fact that vacuum tubes connected to a source of direct current and a special circuit can be made to generate alternating currents of high frequency, commonly called oscillations, is really the foundation of our present broadcasting systems.

If the voice current of Fig. 16B is allowed to regulate the flow of the radio frequency current of Fig. 16C, that is, to “modulate” it, the result is the high frequency current of Fig. 16D, called the modulated oscillating current. This current is no longer of constant amplitude, but its strength varies in exact accordance with the variations in strength and frequency of the voice current, or the spoken sounds. That is, the steady oscillating current is modulated by the voice current. This is accomplished by a vacuum tube known as the modulator tube.

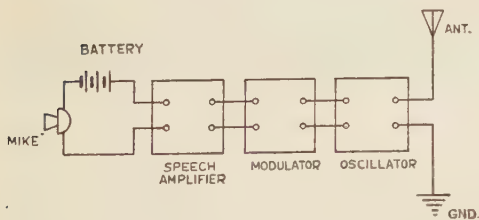


Fig. 20—Fundamental Arrangement of Circuit Elements of a Radio Transmitting Station

A simple analogy which may make the action clear is to think of the oscillating current as a steady stream of water flowing out of the nozzle of a hose. The voice current is represented by an adjustable opening in the nozzle which varies continuously in size. If this variation in the opening is made to take place, the diameter of the stream will be varying constantly to conform to the size of the opening in the nozzle, and it will look somewhat as shown by the dotted outline curves in Fig. 16D.

36. **RADIATION:** The modulated oscillating current goes to the antenna

circuit, where it produces waves which radiate in all directions. The frequency of the waves is the frequency of the high frequency current, so that the frequency or wavelength of the station is controlled by adjusting the oscillator tube circuit. The actual broadcasting equipment is made up of units related to each other as shown in Fig. 20.

The exact way in which the electrostatic and electromagnetic waves travel through space is not completely known. There are many theories attempting to explain their observed behavior, and many of our most able scientists are experimenting constantly to shed new light on its mysteries.



Fig. 21—Interior of a Radio Broadcasting Studio During the Transmission of an Early Morning "Daily Dozen" Program

37. THE BROADCAST STATION: The speakers or artists perform in a studio (Fig. 21) where the microphone is located. This is usually a large room made sound-proof so that no outside noises can affect transmission. The windows are covered with heavy draperies and the walls and floor are padded to improve the acoustic properties of the room and to prevent reverberation, which might cause blasting in the reception of the program. A signal system is included to enable the announcers to communicate with the control room.

Since the amount of current handled by the microphone is necessarily small, it must be amplified in order to be strong enough to affect the modulator tube when impressed upon it. This is done in the control room by a speech amplifier. Since there is very wide variation between the loudness of voices and of musical instruments, the speech amplifier must be capable of adjustment so that when a

particularly loud part of a program comes through, the operator can cut down on the control and not allow as much current to pass through the amplifier. This is necessary in order to avoid overloading of both the transmitting and receiving apparatus and unnaturalness in reception. In most stations it is possible to cut down to a very small fraction of maximum volume. This operation is accomplished continuously by a station operator and is known as monitoring. If the monitor is not quick and constantly on the alert, the loud notes of an orchestra come in like thunder and the low, soft tones are lost entirely.

The next part of the transmitter is the modulator. This is a vacuum tube

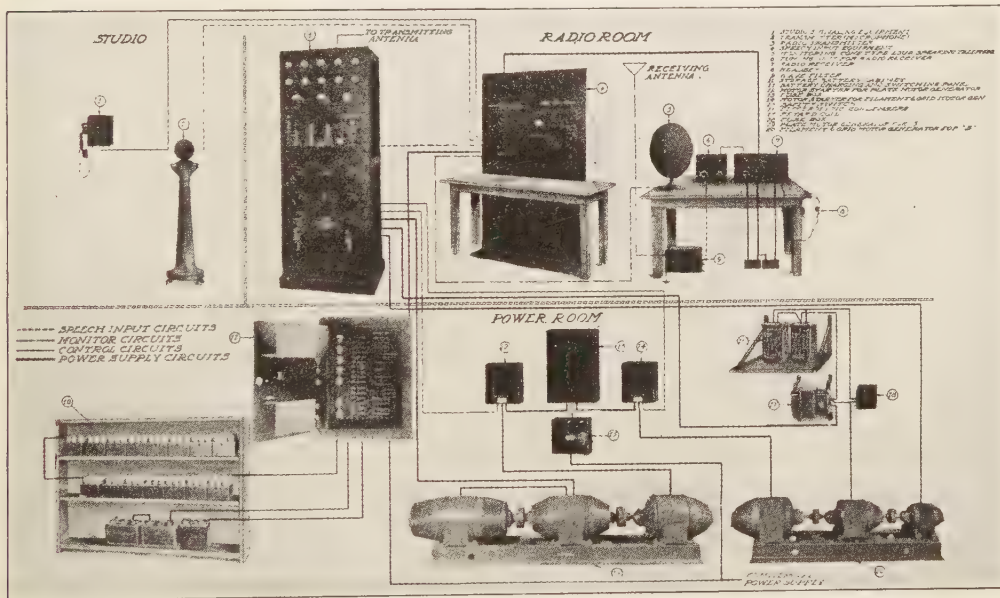


Fig. 22—Pictorial View of Apparatus in a Modern Broadcasting Station

device and in the usual plate power variation, or Heising method of modulation, it varies the plate power going into the oscillator tubes. The oscillator tubes are usually connected in a Meissner circuit for generating high frequency oscillations.

The plate circuits of the vacuum tubes used as oscillators must be supplied with high-voltage, direct-current power. The filaments of all the tubes take quite a large current at low voltage. In order to provide this, some stations employ motor generator sets operating directly from the electric light and power lines. The output passes through a coil and condenser filter combination designed to take out the commutator ripples. Other stations transform low voltage A.C. to high voltage and then rectify it, changing it to direct current by special types of large vacuum tubes called Kenotrons.

The station equipment also includes a receiving set tuned to the wavelengths used in commercial ship work. One operator is constantly on duty at this set to

listen for possible SOS distress signals, so that the broadcast station can be taken off the air immediately upon their reception to avoid possible interference.

38. **REMOTE CONTROL:** If the broadcasting originates at some point removed from the station, as in the case of a football game, the microphones and usually the speech amplifier are installed at the field and a wire telephone line is run to the transmitting apparatus in the broadcasting station. Usually existing telephone lines are rented from the telephone company. Some stations employ a portable radiophone transmitter of low power which is sent to the scene of activity and the program is broadcast directly from there to the main broadcasting station, where it is re-broadcast with increased power.

The accompanying photographs show various parts of station WOR of Newark. The complete equipment for a 1,000-watt station is shown in Fig. 22. The storage batteries are used to operate the speech amplifier and the radio receiving set.

39. **WAVE PROPAGATION:** An explanation of the way in which the radio waves are produced and travel in space enables one to understand and appreciate the wonders of radio transmission and the many difficulties encountered.

We cannot see, hear or feel these waves, but it is possible to visualize their actions by the things they accomplish.

In a previous chapter we found that whenever a current flows through a conductor it sets up a magnetic field around it. Also, whenever a body has an electric charge on it, an electrostatic field is created around it. Let us con-

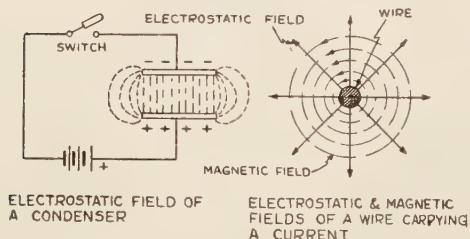


Fig. 23A

Fig. 23B

sider the plates, and the space between the plates, of a condenser. When a condenser is charged, the charge on one of the plates sends out from that plate a large number of lines of electric force which traverse the space between the plates, and end at the other plate, Fig. 23A. These lines of force coming from a charged body are called electrostatic lines of force to distinguish them from electromagnetic lines of force. The space in which these lines occur is called the electrostatic field. The important point to remember is that any conductor which has an electric charge on it has an electrostatic field set up around it. If the charge on the conductor is in motion, in which case there is said to be a current of electricity flowing through it, then the conductor also has a magnetic field set up around it. It is important to remember that the magnetic field does not exist until there is a motion of the charge.

The electrostatic lines of force, Fig. 23B, are radial about the conductor, while the magnetic field is concentric about it. The two fields are always at right angles to each other. The strength of the electric field depends upon the charges. In the antenna, when the current ceases to flow at the end of the cycle, the charge is greatest and the electrostatic field around it is maximum.

When the current has its maximum value, the electric field around the antenna is zero, since at this time the rate of change of the current is a minimum. When

the charges are at rest on a conductor, the electric lines of force are also at rest and extend out radially from it. These lines are supposed to have a certain amount of inertia or resistance to any changes that may take place, so that if the charges on the conductor change rapidly from a condition of movement to one of rest, as is the case in a high frequency alternating current, the lines lag behind and they behave as if they were detached from the antenna, and start to travel away from it at a speed of 186,300 miles per second. This is the radiated electrostatic field which plays the important part in transmission.

Just as the motion of a charge, with its associated electrostatic field, sets up a magnetic induction field around the conductor carrying it, so the motion of the radiated electrostatic field travelling away from the antenna sets up its own magnetic field as it travels. When the radiated electrostatic field is at its maximum value, the magnetic field which it creates is also at its maximum value. It is important to keep clearly in mind the fact that the radiated magnet field which is produced wholly by the moving radiated electric field is entirely distinct from the magnetic field of induction which is produced by the antenna current, and which does not travel any great distance from the antenna. The radiated magnetic field and radiated electrostatic field are closely related. We cannot have the first without the latter.

The two radiated fields move outward from the antenna, at all times perpendicular to each other, the magnetic field being parallel to the ground and the electrostatic field being perpendicular to it. At the same time, both fields are at right angles to the direction of propagation of the waves. At great distances from the antenna, the electric waves would be exactly perpendicular to the earth, if the earth were a perfect conductor. Actually the resistance of the earth's surface causes the waves to tip forward somewhat, as shown in Fig. 19.

Possibly the following description by Dr. Fleming will serve to make this clear:

"If we can imagine a being endowed with a kind of vision enabling him to see the lines of electric strain and magnetic flux in space, he, standing at any spot on the earth's surface, would see, when the antenna was in action, bunches or groups of electric strain fly past. Near the earth's surface these strain lines would be vertical. Alternate groups of lines of strain would be oppositely directed, and the spectator would also see groups of magnetic flux fly past, directed in a horizontal direction or parallel to the earth's surface. The strain and flux lines would move with the velocity of light, 186,300 miles per second, or 300,000,000 meters per second, and the distance between two successive maxima of electric strain, directed in the same direction, would be the wavelength of the wave."

At the receiving station the antenna may take the form of an open wire or a loop. In either case the radiated waves from the transmitter striking across it, cause currents of electricity to flow in the receiving circuit. This will be studied in detail later.

40. **FADING OF SIGNALS:** In some localities the signals from certain stations, especially short wave stations, seem to fade in and out in an irregular manner. This usually is more marked at night than in the daytime. The probable explanation of this curious phenomenon is that as the waves travel outward from

the transmitting antenna, they may be considered as taking the form of ground waves and sky waves. The ground wave is greatly weakened as it travels through obstructions like frameworks of steel buildings, etc. The sky wave apparently goes up into the air perhaps fifty or a hundred miles and is reflected so that it comes down again to combine with the other wave which has travelled along the earth. The two waves arriving at the receiving aerial combine to produce the resulting wave which affects the receiving apparatus. Since the sky waves travel a much longer distance than the ground waves (Fig. 24), it is possible that the

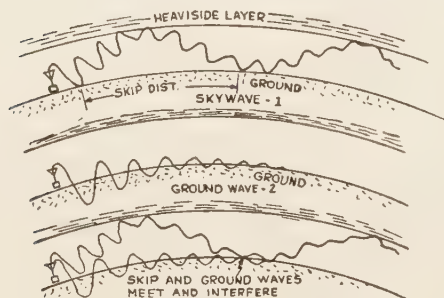


Fig. 24—Fading and Skipping Action of Radiated Radio Waves

two are not in phase with each other when they meet. When they are both in the same phase at the time of meeting, the resultant signal is strong; when they differ in phase the resulting signal is weak. The constant minute-to-minute variation in distance travelled, changes the phase relation with consequent fading or swinging of the signal. Fading is a function of frequency, being more troublesome as the frequency is increased. It is more pronounced at night than during the day and decreases as the distance from the transmitter is increased. The

reflection action on the sky wave is explained by a theory advanced by Sir Oliver Heaviside.

41. **HEAVISIDE LAYER:** Seventy-five or a hundred miles up, the atmosphere surrounding the earth is very rare. The molecules, consisting of equal positive and negative electrical charges, are split up—"ionized" into positive and negative portions by the ultra-violet light from the sun during the day. This ionized layer of atmosphere is a conductor, and is known as the Heaviside layer. During the day the layer comes closer to the earth because of additional ionization of the molecules by the sun. At night, during the absence of the sun, the positive and negative portions of a part of the molecules reunite, and the layer rises from the earth. During the day the sky wave is very materially reduced by absorption from the conducting Heaviside layer, and so practically all of the energy comes through the ground waves, to all but those receiving stations located close to the transmitting station. At night, both the ground and sky waves are stronger so the receiver signal is much stronger.

42. **SKIPPING:** The Heaviside layer is always present then, but at varying heights, depending on the sunlight and changes in barometric pressure. Due to the varying height and possible uneven surface at places, the angle of reflection of the sky wave is constantly changing so that the phase relation between the ground and sky wave changes, with consequent fading. With very high frequency (low wavelengths) this effect of the Heaviside layer is so marked that the radio waves appear to skip over certain localities entirely, and reception in those places is impossible. That is, the intensity of received signals first decreases as the distance from the transmitter is increased, reaching a value too low to be detected. As the distance is further increased, the signals become readable again. The skip distance

at night is much greater than in the daytime. It gradually increases up to about midnight. It is also greater in winter than in summer, because the ionization is less then due to shorter periods of sunlight.

It has been found that on 15 meters the daylight skip is about 900 miles and is about 1,000 miles at night. On 27 meters the day skip is 100 miles and night skip is 450 miles. On 33 meters the day skip is 100 miles and night skip is 400 miles. On 50.2 meters there is no apparent skip. The amount of skip increases as the wavelength is increased, and above about 150 meters the effect is negligible, so broadcasting stations are not affected.

About an hour before sunset there usually occurs a rise in the average intensity of radio signals, then a drop at sunset, and a rise to a first maximum about an hour later. During the night the average intensity varies, but shows its greatest value about two hours before sunrise. The sunrise effect is similar to the sunset effect, but reversed.

REVIEW QUESTIONS.

1. Describe the action of the microphone.
2. Describe the process of modulation.
3. How are programs originating at points outside the broadcasting studio broadcast?
4. Explain how radio waves are propagated.
5. What is the theory regarding the fading and skipping action of radio waves?
6. Why does the "skip distance" vary throughout the day and night?

CHAPTER 4.

THE RECEIVING STATION, DETECTION WITH CRYSTALS.

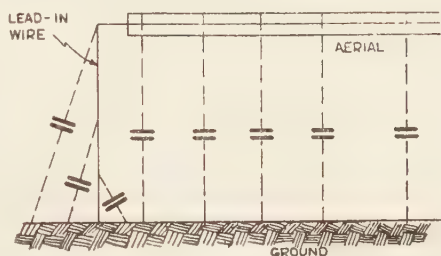
RECEIVING—EARPHONES—EARPHONE OPERATION—DETECTION—CRYSTAL DETECTION
—IMPROVED DETECTION—AMPLIFICATION AND SELECTIVITY—TUNING—SINGLE
CIRCUIT RECEIVER—TWO CIRCUIT RECEIVER—CARBORUNDUM DETECTOR—
CONSTRUCTING A CRYSTAL SET—MEASURING CRYSTAL CHAR-
ACTERISTICS—LIMITATIONS OF CRYSTAL SETS.

43. **RECEIVING:** At the receiving station the radio waves in the air are separated, amplified, and made to reproduce as faithfully as possible the original program from the radio station it is desired to receive. It will be remembered from the previous chapter that the modulated high-frequency current flowing in the antenna circuit of the broadcasting station sets up an electrostatic and an associated electromagnetic field, which travel outward in space in all directions at about 186,000 miles or 300,000,000 meters per second. As the fields spread out continuously over a larger and larger area, their intensity decreases as the distance from the station increases. When they reach a receiving antenna or aerial of the common type, consisting of one or more elevated wires, the electrostatic field sets up an alternating voltage between the wires and the ground. If the circuit between the antenna and ground is complete, this e.m.f. causes a current of the same frequency as that of the broadcasting station to flow, the strength of the current being determined by the impedance of the circuit.

Of course, as the radio waves spread out in all directions from the transmitting station their strength naturally decreases. At twice the distance their amplitude is halved, at four times the distance it is only one quarter. The strength is inversely proportional to the distance. There is also a decrease in strength due to the fact that whenever the waves strike any object in which they can produce electric current (such as the steel framework of a building), currents are produced at the expense of the energy of the waves and heat up, to a minute degree, the material in which they flow. This dissipation of energy acts simultaneously with the inverse distance effect to reduce the strength of the waves and the signals received, as the distance from the transmitter increases. The latter effect is especially great around large cities like New York, Chicago, etc., and is one of the reasons for poor "distance" reception in these cities.

The current, however, is practically an exact duplicate, as regards wave form, of that sent out from the broadcasting station. It is possible by means of certain apparatus to convert this current back into sound waves similar to those put into the microphone at the studio.

It may be said that with the ordinary antenna system at the receiving station, the potential is produced by the sweeping action of the moving electrostatic field on the exposed aerial and ground, as the intensity of the impinging lines of force varies and changes in direction, at the same time frequency as the waves. The aerial and ground really form a condenser, having the aerial wire as one plate, the ground as the other plate and the air between them as a dielectric. This is a complete circuit and an alternating current will flow in it when an alternating voltage is introduced (Fig. 25).



FORMATION OF CONDENSER BETWEEN AERIAL AND GROUND

Fig. 25

If a loop antenna is used at the receiving station, the current set up is due practically entirely to the action of the electromagnetic field. This will be discussed in greater detail when explaining the loop antennas.

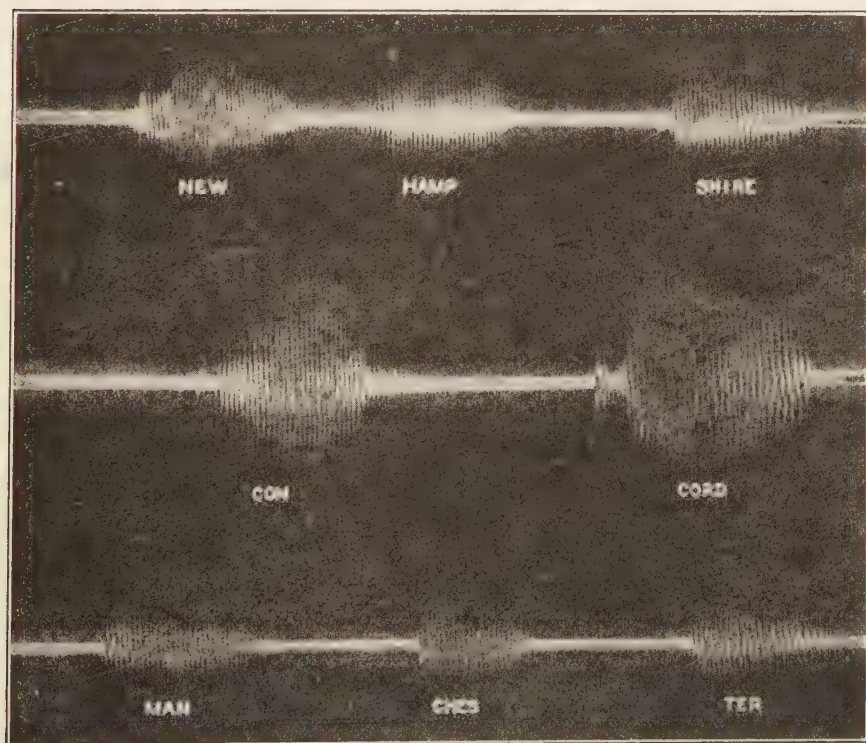
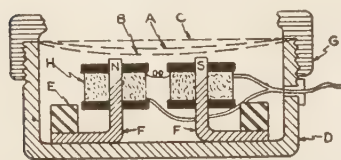


Fig. 26—Oscillograph Photograph of a Carrier Wave Modulated by the Words "New Hampshire," "Concord" and "Manchester"

The object of the receiving apparatus is to amplify and convert the antenna current into corresponding sound waves. Some idea of the complexity of the current impulses transmitted when speech and music are broadcast can be gained from the photograph of Fig. 26, which shows the modulated carrier currents for the words New Hampshire, Concord, and Manchester. These are reproduced here by courtesy of the American Telephone and Telegraph Company.

44. **EARPHONES:** In the ordinary telephone, the current is changed into sound by means of the telephone receiver. The same type of instrument, modified slightly, can be used for radio reception. It is commonly known as the headset or earphones. Earphones, like the ordinary telephone receiver, operate on the electromagnetic principle. However, they are made much more sensitive than those used in telephone work, as the radio currents are usually much weaker than those encountered in telephone work, and therefore cannot exert much force.



EARPHONE

Fig. 27

They usually consist of two separate earpieces connected in series and held to the ears by a metal headband. Each earpiece has a metal or hard rubber cup. D, Fig. 27, with a hard rubber cap G. In the bottom of the cup is a strong permanent horseshoe magnet E, with pole pieces F. Around each pole piece, a coil H, of many thousands of turns of fine insulated wire (No. 40 to 50) is wound. The

two coils are connected in series, so the current passes through both windings. Sensitive headsets have 10,000 or more turns of wire on the coils, so that even very feeble currents flowing through them produce an appreciable magnetic field. Suspended above the pole pieces, and very close to them, is a thin, flexible, soft iron diaphragm about .004 inch thick. A commercial set of earphones with headband is shown in Fig. 28. The phone on the right has been opened to show the screw cap (center) and the diaphragm (right).

45. **EARPHONE OPERATION:** When no current flows through the coil, the magnetism of the permanent magnet attracts the iron diaphragm and bends it slightly, as shown by position A in Fig. 27, producing an initial deflection. Assume the left-hand pole piece to be a North pole and the right-hand one a South pole. If one complete wave of an alternating current is flowing through the receiver, so that the current during the first half of the wave flows through the coils in such a direction as to produce magnet poles similar to those of the magnets, then this magnetism adds to that of magnets and the field is strengthened. This increases the attraction on the diaphragm and pulls it down further, to point B. On the next half wave, the direction of the current reverses, and so the magnetic field produced by its flow through the coils also reverses, and opposes that of the permanent magnet. The resultant field is now weaker than that of the magnet alone, so the diaphragm springs back to position C. At the end of the cycle it goes back to A. Therefore, during one cycle it makes a complete vibration from A to B to C, depending on the amount of variation of current flowing through the coils. This back-and-forth movement of the diaphragm sets the air in motion and creates sound waves that travel out through the opening in the cap. If the frequency of these

waves lies within the audible range—about 16 to 20,000 cycles—they can be heard by the human ear.

At first thought it might seem that the currents set up in the antenna circuit could be changed into sound waves directly by connecting a pair of earphones in it, as shown in Fig. 29. This would not work, as is evident from the following considerations.

46. NEED FOR DETECTION:

In order to transmit the broadcast programs over a considerable distance, it has been found necessary to use carrier currents of high frequencies, because they are capable of being radiated into space. They are modulated by the currents of voice frequency. The carrier current frequencies used in most broadcasting at the present time range from 1,500,000 to 500,000 cycles, corresponding to 200 to 600 meters, respectively. The range of frequencies to which the ordinary human ear will respond is from 16 to 20,000 cycles. Therefore, even if the high frequency current received by the antenna could be made to flow through the earphones, and the diaphragm made a complete vibration for each cycle, it would be vibrating so rapidly that the ear would not respond to it. Actually, it is impossible for the diaphragm, which is not perfectly flexible and has some inertia, to vibrate this fast. And lastly, the magnet coils of the earphones, having a necessarily large inductance due to the great number of turns of wire wound on an iron core, offer a very high impedance-opposition to the current flow (to currents of such high frequency); so that practically no current at such high frequencies is able to flow through them anyway. A set of earphones having a direct current resistance of 2,000 ohms may have an impedance as great as four or five thousand ohms at a frequency of only 1,000 cycles. It is evident from these considerations that the circuit shown in Fig. 29 is impractical.

To make the signal audible, and the voice currents heard, the circuit must be arranged so the diaphragm does not follow the current variations in each individual cycle of the carrier wave, since this is a high frequency and we are not interested in hearing it. The diaphragm must be made to follow the variations in the maximum strength of the current in one direction; i. e., follow the wave form or envelope of the high frequency current, Fig. 30A. This, it will be remembered, is the true wave form of the voice waves. To do this, it is necessary to make only



Fig. 28—A Pair of Standard Earphones



Fig. 29—Elementary Receiving Circuit

one or the other half of the alternations effective, so the current flows through the earphone coils in one direction only. This is accomplished by the detector, and the process of cutting off or eliminating half of the received wave is called rectification or detection.

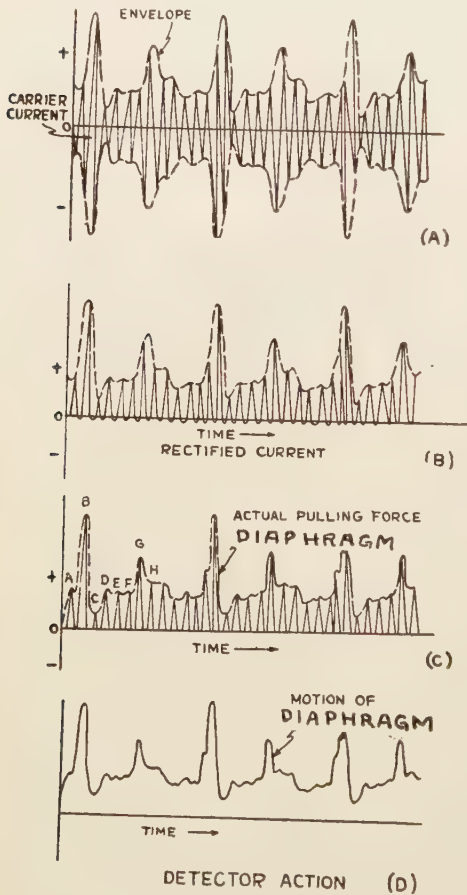


Fig. 30

It is the difference in strength of these two currents which determine how well or how poorly the crystal operates as a detector. A good crystal will eliminate the current in one direction practically entirely. Fig. 32 shows a commercial form of crystal detector used in the early days of radio.

48. **DETECTION:** The pulses or fluctuations of current would still seem to be too rapid to actuate the diaphragm, since their frequency is that of the carrier current. Their effect on the receiver diaphragm, however, is for each wave train to give force by successive addition, as can be seen from the following. The first impulse A, Fig. 30C, passes through the earphone coils and produces a movement

47. CRYSTAL DETECTOR:

The simplest rectifier is the common crystal detector, Fig. 31. This usually consists of a very fine wire called a cat-whisker, making light contact with a crystal of a particular mineral, such as galena. Other mineral combinations can be used, but for our purpose of explanation the galena detector will suffice.

When an alternating voltage is applied to the combination, it tends to make current flow from the catwhisker to the crystal (Fig. 31), during the first half cycle. The resistance which the crystal and contact offer to current flow in this direction is low so the current is able to flow through easily. On the next half cycle the voltage is reversed and tends to send current in the opposite direction. The detector contact offers a very high resistance to current flow in this direction, so very little current is allowed through. The action is repeated for each cycle. This is shown graphically in Fig. 30A and B, where A is the impressed alternating current and B is the rectified pulsating current.

Notice that practically all of the current in the direction represented below the axis line has been eliminated and that which does net through, flowing from cat-whisker to crystal, consists of a series of pulses of current of varying amplitude.

of the diaphragm. If the station is transmitting at say 200 meters, corresponding to a frequency of 1,500,000 cycles per second, then the time interval between two successive maximum values of current, as A and B, is one one-million five hundred thousandth of a second. Obviously, since the diaphragm has inertia and stiffness, it is somewhat sluggish in action and cannot possibly make a complete vibration in this time, so the second impulse B will occur before the diaphragm has had time to spring back in place, and will therefore deflect it further. So will the following impulses C, D, E, etc., the result being that the diaphragm is deflected once for every wave train and its motion follows more or less faithfully the shape of the envelope of the carrier current, as shown in Fig. 30C. Since this is the same shape as the wave form of the sound impressed at the broadcasting station, the movement of the diaphragm sets up similar sound waves which can be heard by the listener at the receiving station. The changing of the electric currents induced in the aerial into corresponding sound waves is accomplished in this way, and the circuit is shown in Fig. 33.

Crystal detectors are not used much

at present, having been supplanted almost entirely by the vacuum-tube detector.

49. IMPROVED DETECTION: Fig. 33 represents one of the simplest basic receiving circuits. The volume, and frequently the quality, of the sound in the receivers is improved by connecting a small fixed condenser C of about .0005 mfd. capacity across them, as shown in Fig. 34A.

The operation is then as follows: During the duration of one impulse A of the rectified current of Figs. 30C and 34B, the current flows through the earphone coils and also charges the condenser C. During the next half cycle no current flows through the detector D. At this instant the condenser C, however, being connected across the phone coils and having an electric charge on it, partially discharges through them. The discharge current of the condenser is in the same direction as that of the impulse A. This acts to keep the diaphragm in position until the next impulse B comes along. The current flowing in the telephone receiver is then like that shown in the somewhat enlarged and exaggerated drawing in Fig. 34B. There is, then, during each wave train a more continuous attraction on the earphone diaphragm, with resulting improved reproduction, since the diaphragm follows more nearly the outside curve or envelope of the current.

In most modern earphones there is some capacity existing between the individual turns of wire on the coils, and the usual five-foot external connection leads being close together also form a condenser. This combined

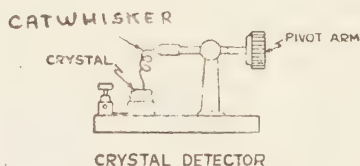


Fig. 31

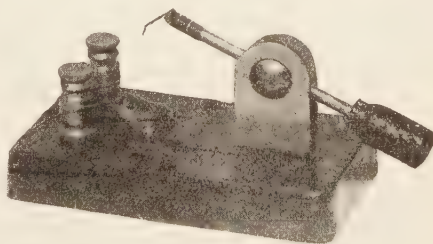


Fig. 32—Old Fashioned Crystal Detector



Fig. 33

capacity is usually enough to give the above action, so that no additional condenser C is necessary. In diagrams in future chapters the condensers will be omitted, although the reader should remember that a capacity really does exist there.

50. **AMPLIFICATION AND SELECTIVITY:** It is evident that the circuit of Fig. 34A will respond to waves from any station, provided enough current is induced in the antenna circuit by these waves to operate the phones. This suggests at once the two important shortcomings of this arrangement. Since it will respond only to waves of comparatively great strength, its receiving range is limited to 5 to 25 miles, depending on local conditions. As there are hundreds of broadcasting stations, many of them in the same city, if several of them transmit

at the same time with enough power to permit of reception by the crystal set, they will all be received together, creating interference, and reception will be anything but pleasant.

These facts make it evident that if programs from distant stations are to be heard, some form of amplifying device must be employed to strengthen the currents induced in the antenna circuit. This will be considered later. Since it is desired to hear only one station at a time, some provision must also be made for selecting the program of any one station to the exclusion of all others. This is accomplished by having all the stations in the same locality operate with carrier currents of different frequencies or wavelengths.

Thus in New York City, station WEA

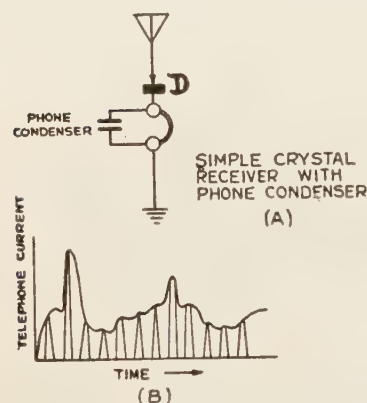


Fig. 34

transmits with a carrier wave frequency of 660 kilocycles (454 meters); WJZ with 760 kilocycles (395 meters); WOR with 710 kilocycles (422 meters), etc. These frequencies are assigned to stations by the Federal Radio Commission. Some stations located in the same city are assigned the same frequency, but they do not broadcast simultaneously.

51. **TUNING:** In order to select the station desired and exclude all others which may be transmitting at the time, some means must be provided for excluding the induced currents of the frequencies of the stations not wanted, and at the same time to allow the currents of the frequency of the desired station to flow through the receiving apparatus. The ability of a receiving set to do this satisfactorily is a measure of its selectivity. This is called tuning and the process is commonly spoken of as tuning in a station. Practically all tuning in radio sets at the present time is accomplished by making use of the resonance effect of alternating currents explained in Chapter 2, to reduce the impedance of the circuit to a minimum for the particular frequency which is to be received.

The circuit of Fig. 34A can be roughly tuned to any frequency by the introduction of an inductance coil C (Fig. 35), consisting of a number of turns of insulated wire wound on a cylindrical form. A sliding contact is arranged to make connection with any number of turns of the coil. The inductance is increased

or decreased by increasing or decreasing the number of turns respectively. By moving the slider, more or less inductance can be inserted in series with the antenna, thereby changing the frequency to which the circuit will respond most strongly, and the station it will receive. This receiver is not selective enough for present-day use. Since the crystal detector and phones have a high resistance and they are in the path of the antenna circuit, the tuning is very broad and the volume is poor.

52. SINGLE CIRCUIT RECEIVER: The tuning can be sharpened considerably by removing the detector and phone resistance from the antenna circuit and putting them in a circuit by themselves, as in Fig. 36. Coil C has two sliding contacts. The antenna circuit includes all the turns of wire between 1 and 2, while the secondary circuit, containing the crystal detector and receivers, includes the turns between 2 and 3. It is thus possible to tune both the antenna and secondary circuit to the proper frequency. This is known as the single circuit receiver.

53. TWO CIRCUIT RECEIVER: The single circuit crystal receiver is not usually selective enough in congested districts where many stations are operating at once on frequencies which are close together. As will be explained later, in order to get maximum response and maximum selectivity it is important to keep the resistance of the antenna and tuned circuits to a minimum, provided this does not have an unsatisfactory effect on the receiver as a whole in some other way. To do this with a crystal receiver, the crystal and phones are placed in a secondary tuned circuit, coupled in some way to the aerial circuit, the latter responding to the maximum degree to the incoming signals. Such a circuit is shown in Fig. 37, and is known as a two circuit receiver. The primary and secondary coils of the inductance L are wound near each other (usually on the same form), so that the magnetic field produced by the antenna current flowing through the primary coil links and unlinks with the turns of wire of the secondary and induces a similar current in it.

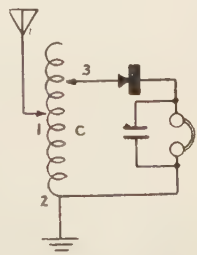
The variable condenser C, connected across the secondary coil, tunes the coil and produces resonance in the circuit. This makes the passage for these infinitesimally small currents as easy as possible, thus greatly increasing the current in the tuned circuit LC. This sets up the largest possible potential differences across the coil and condenser and since these are applied to the detector and earphones, causes an increase in volume over that produced if the circuit were not tuned. The primary circuit can be tuned independently by the taps which vary the number of turns included in the aerial-ground circuit. By varying the taps and the settings of the variable condenser, the circuit will respond to any desired frequency within the range for which the coil and condenser have been designed.

54. CARBORUNDUM DETECTOR: The Carborundum crystal detector has become very popular as a rectifier due to its very stable operating characteristics.



TUNING INDUCTANCE
IN AERIAL CIRCUIT

Fig. 35



SINGLE CIRCUIT
CRYSTAL RECEIVER

Fig. 36

Fig. 38 shows a view of a commercial form of carborundum detector cut open to expose the various parts. It consists of a crystal of carborundum held in contact with a slug of metal under a pressure of about five pounds by a compression spring. The pressure may be regulated for best operation by the pressure adjusting screw which comes out at one end. The entire unit is enclosed in an insulated protective casing. This combination offers a very low resistance to the flow of current from slug to crystal, but presents a very high resistance to current flow from crystal to slug, thus acting as a detector or "rectifier."

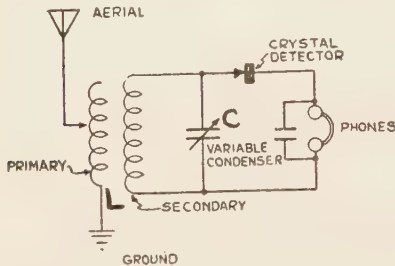


Fig. 37—Two Circuit Receiver

preferable as it gives much better selectivity with very little loss in efficiency, when the tap is properly located.

55. CONSTRUCTING A CRYSTAL SET: A very cheap and efficient crystal set for earphone reception can be constructed from the circuit diagram in Fig. 40. The primary coil P consists of a total of 32 turns of No. 28 B. and S. gauge double silk or cotton covered copper wire wound in a single layer on a tube four inches long and two inches in outside diameter. The coil is tapped at

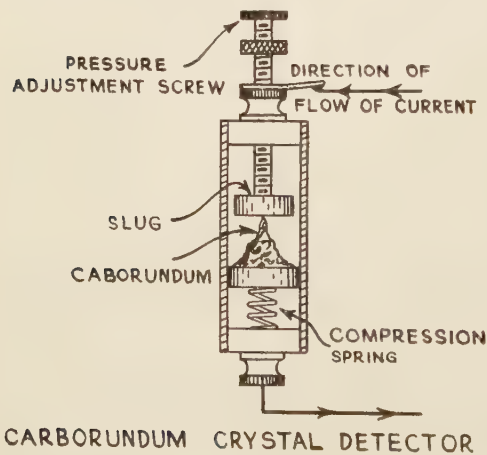


Fig. 38

Fig. 39 shows two practical circuits for a Carborundum detector. In 39A the rectifier is placed across the entire tuned circuit. In 39B the rectifier is placed across only a portion of the circuit. The arrangement in B is

2, 4, 8 and 16 turns. In winding the coil, twists should be made for each turn from which taps are made, so as to make connections to the taps easy. The secondary coil consists of 90 turns of No. 28 D. C. C. wire wound in a single layer on the tube next to the primary and separated from it by $\frac{1}{8}$ inch. A tap is made at the 20th and 45th turn. The tap which gives best volume consistent with good selectivity should be used. An aerial from 75 to 100 feet long should be employed. Tuning is accomplished by the .00035 mfd. capacity variable condenser. The phones are by-passed by a .001 mfd. fixed condenser. The Carborundum crystal should be connected as shown.

Adjustment for best selectivity can be made by operating the set with the ground connected to the various taps of the primary coil in turn.

56. MEASURING CRYSTAL CHARACTERISTICS: The operating characteristics of crystal detectors can be determined easily by the arrangement

shown in Fig. 41A. The battery is single $1\frac{1}{2}$ volt dry cell. The voltmeter is a good low reading instrument sufficient to register the voltage of the battery. The milliammeter has a range from 0 to 1 milliampere. The 200 ohm potentiometer P is used to apply any definite voltage to the crystal. The milliammeter measures the current which the crystal allows to flow. The reversing switch S is used to apply either a positive or negative potential to the detector. The potentiometer is set for voltage steps of 0.1 volt and the corresponding currents are read on the milliammeter. This is done for both positive and negative voltages.

In Fig. 41B, a graph of current flow against applied voltage is shown for the carborundum crystal detector of Fig. 38. Curve A-B is for the e.m.f. in the positive direction (+ terminal to slug). Curve A-C is for the e.m.f. in the negative direction (+ terminal to crystal). Notice that practically no current flows through the crystal in this direction (unless the applied voltage is made quite high). This illustrates the rectifying properties of the crystal.

Most crystal detectors can be roughly checked for rectification by connecting a dry cell ($1\frac{1}{2}$ volt), pair of phones and the detector in series. A strong click should be heard when the detector is connected in one direction, and almost no click when reversed. This indicates that the detector rectifies properly.

57. LIMITATIONS OF CRYSTAL SETS: This gives us a system of radio reception in which the volume of sound produced depends entirely on the strength of the received waves. Since the amount of energy decreases very rapidly as the distance from the transmitting station is increased, it is evident that simple crystal sets cannot be used for long distance reception, because the received currents are not strong enough to operate the earphones.

The use of earphones is becoming unpopular, as people desire to hear their

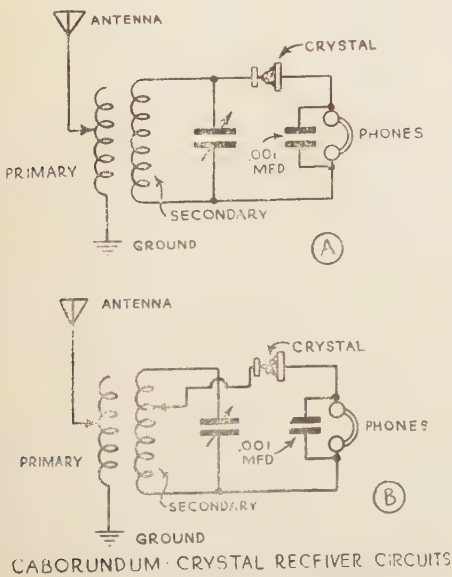


Fig. 39

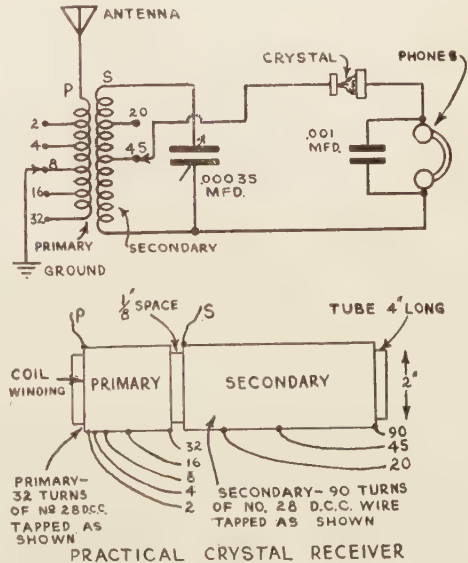


Fig. 40

programs in comfort with loud speakers which produce enough volume to fill good sized rooms. Loud speakers require a stronger operating current than do ordinary earphones, so amplifiers have been developed for amplifying the received radio currents to make loud speaker operation possible. These employ vacuum tubes in their operation. The crystal detector, while producing remarkable clarity of reception, is unable to handle either very weak or very strong impulses of current satisfactorily.

Crystal detectors have been superseded almost entirely by vacuum tube detectors, due to their greater selectivity, ease of adjustment, and property of not only rectifying but amplifying at the same time. The rectifying ability of a crystal is an inherent property of the crystal and cannot usually be altered or improved. The point of best selectivity must be determined by trial by moving the catwhisker over the surface of the crystal. In most cases, this point is never located. The adjustment is not permanent, and heavy currents such as those received from powerful nearby broadcasting stations may make the detector inoperative by setting up a comparatively great amount of heat at the contact point, thus oxidizing the conducting properties. The use of the Carborundum crystal detector eliminates the adjustment difficulties. Some receivers have been devised for the use of a carborundum crystal detector with radio and audio frequency amplifiers employing vacuum tubes. Such hybrid receivers are capable of very fine performance if correctly designed.

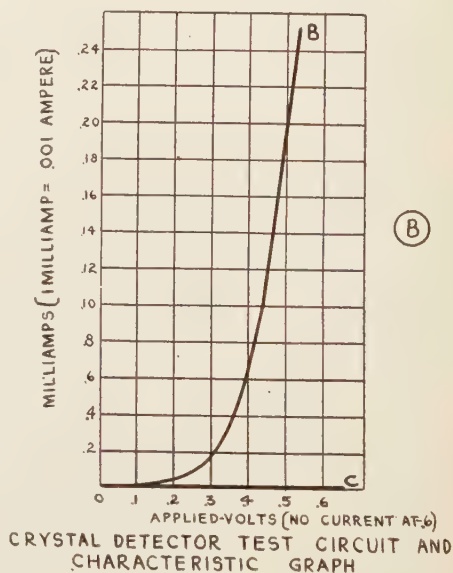
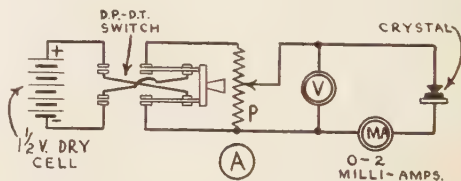


Fig. 41

REVIEW QUESTIONS.

1. Describe the process of radio reception.
2. Explain the action of the ordinary earphone.
3. Why is "detection" necessary in a radio receiver?
4. Why are crystal detectors not used very extensively in modern radio receivers?
5. Draw a circuit diagram of a simple crystal receiver, and explain the action of the various parts.
6. Why is amplification necessary in the modern receiver?
7. What is meant by "tuning" and how is it accomplished?
8. What advantage does the two-circuit receiver possess over the single-circuit receiver?
9. What are some of the advantages of the carborundum crystal detector?
10. State three limitations of crystal receivers.

CHAPTER 5.

DESCRIBING THE ACTION OF THE VACUUM TUBE, AND CLEARING UP SOME OF ITS MYSTERIES.

VACUUM TUBES — EDISON-EFFECT — ELECTRON THEORY — ELECTRON EMISSION —
TWO ELECTRODE TUBE—SATURATION—SPACE-CHARGE—RECTIFIER—THREE
ELECTRODE TUBE—AMPLIFYING—CHARACTERISTIC CURVES—EFFECT
OF GAS—HARD AND SOFT TUBES.

58. **VACUUM TUBES:** Possibly the greatest single invention in radio has been that of the vacuum tube (commonly called audion, valve, or bulb). This versatile instrument, which is daily opening up new fields of application for itself in numerous branches of the industrial world, is the backbone of the present radio art. It is used in transmitting stations for rectifying alternating currents, and for generating and modulating high frequency currents. In the modern receiver, vacuum tubes are employed for rectifying and amplifying the weak currents received by the antenna. They have also aided materially in solving the "A" and "B" battery elimination problem, by their use as rectifiers.

A vacuum tube resembles an ordinary electric light bulb somewhat, but contains additional elements inside. A network of wires known as the grid surrounds the filament, and a strip of metal called the plate, encloses the grid. Connections to the various elements are made by prongs extending from the insulating base, Fig. 46. The operation of the three electrode vacuum tube as a detector and an amplifier can be better understood by first studying the various fundamental phenomena which control its action.

59. **EDISON-EFFECT:** In 1884 Thomas A. Edison, during the course of investigations on his incandescent lamp, discovered that when he took an ordinary incandescent lamp containing a filament, and introduced a second cold wire called a plate, insulated from the filament and maintained at a potential positive with respect to the negative end of the latter, current flowed from this wire across the vacuum to the filament as long as the filament was hot and incandescent. The current ceased as soon as the filament was allowed to become cold. If the wire was maintained at a negative potential with respect to the filament, no current flowed. This action has generally become known as the "Edison-Effect."

The effect was unusual but not deemed important at the time. It was studied again years later by several other investigators.

60. **ELECTRON THEORY:** The underlying principle governing the action is the electron theory of matter and electricity. According to this theory all substances consist of myriads of atoms. Each atom in turn is made up of

a center nucleus having a positive charge of electricity, around which revolves a number of small negative charges called electrons, shown in an elementary way in *A* of Fig. 42. Under normal conditions the positive charge of the nucleus is equal to the sum total of the negative charges around it, so that a state of balance exists and there is no external electrical manifestation. The chemical nature of the atom depends on the number and arrangement of its atoms, and the value of the positive charge of the nucleus of an element expressed in terms of the unit of electric charge is called the atomic number of the element. At least one of these electrons is loose or free to circulate around among its neighbors, the number increasing with the conductivity of the substance.

61. **ELECTRON EMISSION:** As the temperature of the substance rises from absolute zero (-273 degrees Centigrade) the molecules become agitated and begin to vibrate, their velocity increasing greatly as the temperature is raised. When the temperature is high it is relatively easier for the free, wandering

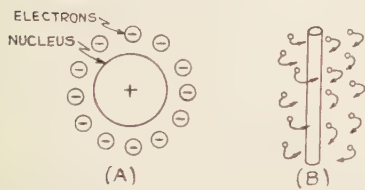


Fig. 42—Elementary Structure of an Atom

electrons to become detached from their groups and some of them, near the surface of the substance, break through the surface tension of the metal and are thrown off into space, that is, the metal tends to evaporate (just as water evaporates at ordinary temperatures). Thus there is an emission of free electrons from a heated body out into the surrounding space, forming a sort of cloud around it. To actually produce the evaporation of ordinary metals requires that they be heated to the very high

temperatures in a vacuum, for otherwise they combine with the oxygen of the air and "burn up." Some substances give off electrons more freely than others, and at lower temperatures, as we shall see later.

When the electrons separate from the atom, the charge on the nucleus more than balances that of the remaining electrons, so that in an isolated body the free electrons are thrown off into space for a short distance and are attracted back by the unbalanced positive charge on the nucleus, somewhat as shown in *B* of Fig. 42.

As the temperature is raised, the agitation of the atoms increases and electrons are boiled off into space at a faster rate. As the electrons are negative charges of electricity, if a cold positively charged body is placed near the hot substance emitting the electrons, they will be attracted to it (in accordance with the fundamental law of electrostatics that unlike charges attract), and will travel from the hot body to the positively charged body. These electrons so attracted will be returned to the filament through the external plate circuit. The space between the two bodies is then filled with a stream of free electrons moving from the hot body to the cold one, Fig. 44. The second body must be relatively cold so it does not also emit electrons. It was shown in Chapter 2 that free electrons in motion constitute an electric current, the direction of the current flow conventionally being considered as opposite to that of the electron flow. This means that an electric current ("plate current") is established in the intervening space, through the filament, and through the external plate circuit.

62. **TWO ELECTRODE VACUUM TUBE:** In 1890 Dr. J. A. Fleming made practical use of the Edison-effect in his two-electrode vacuum tube, Fig. 43A. *F* is a metal filament heated to incandescence by a source of current *A*, the current being controlled by a resistance *R*. "*B*" is a battery (source of potential) connected between the plate *P* and the filament. It serves to maintain the plate electrically positive with respect to the filament. Both the plate and filament are sealed in an evacuated glass bulb to prevent oxidation or burning up of the white hot filament and to remove any air or other gas atoms which would interfere with the movement of the electrons, as explained later. As the filament is giving off free electrons and the plate has a positive potential, there is a flow of electrons from the filament to the plate, called the "plate current."

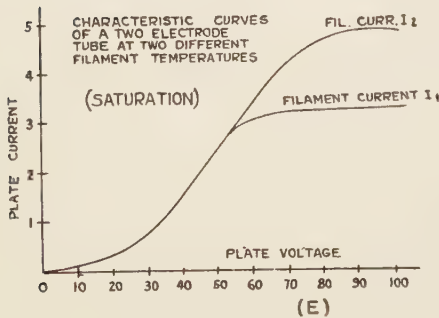
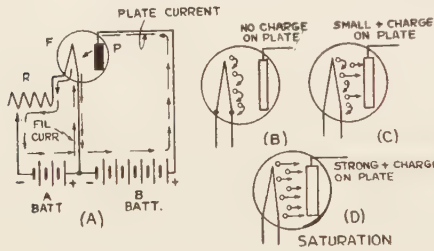


Fig. 43—Action and Saturation Characteristic of a 2 Electrode Tube

63. SATURATION CURRENT:

If the filament temperature is kept constant, the number of electrons emitted by it per second will be constant. Some of these electrons are attracted to the plate by the positive plate charge and others go out into space for a short distance, only to be attracted back to the filament by the unbalanced electrical charge of the atoms, as shown in Fig. 43C.

The proportion of the electrons attracted to the plate depends on the magnitude of the plate potential. When the filament temperature is kept at a constant value, and the plate potential is gradually increased, the number of electrons reaching the plate, and therefore the current in the plate circuit, will gradually increase. This will continue until a condition is reached where all of the emitted electrons are drawn over to the plate (Fig. 4D), so that a further increase of plate potential will not result

in any increase of plate current. This maximum plate current, beyond which there is no increase for increased plate potential, is known as the saturation current of the tube for the corresponding filament temperature or plate voltage.

If the plate current is to be increased beyond this point, the filament temperature must be raised, thereby increasing the electron emission. For any given filament temperature then, there is a definite value of maximum plate current which can be obtained, occurring when the plate attracts the electrons at the same rate that they are emitted.

The action is shown by the graphs of Fig. 43E, where the plate potentials or voltage are laid out along the horizontal axis and the plate currents along the vertical axis. It will be seen that, for any fixed filament current or temperature,

as the plate potential is increased the plate current rises up to the saturation point, where the curve bends over and becomes horizontal. It is evident that in order to obtain at the plate all of the emitted electrons, a certain maximum voltage must be impressed on the plate; increasing it beyond this does not result in any gain.

64. **SPACE CHARGE:** Now consider a tube with fixed plate potential. When the filament is cold, since no electrons are being emitted, there is no current in the plate circuit, Fig. 44A. If the filament is gradually heated, by increasing the current from the "A" battery, it begins to give off electrons when it has attained a dull red heat, Fig. 44B. The number of electrons emitted by the filament increases approximately as the square of the excess filament temperature above red heat.

At any instant the space between the hot filament and plate contains those emitted electrons moving on toward the plate, to be absorbed there. As the filament current is increased, Fig. 44C and 44D, the rate of emission of these electrons increases, so that at any instant the number of electrons present in the space between the filament and the plate depends on the rate of emission by the filament and the rate of attraction by the plate. The steady increase of filament temperature increases the electron emission from the filament and also the number in the space. As these electrons are negative charges of electricity, they act upon each other in accordance with the well-known laws regarding electric charges, mentioned previously.

In Fig. 44E let *A*, *B* and *C* be three electrons occupying different positions in the space between the filament and plate. Electron *C* is attracted by the positive charge on the plate, and is repelled toward the plate by the negative charges of all the electrons back of it, since they have like charges. Therefore, it will undoubtedly go to the plate. Electron *B* is attracted by the plate, and repelled back by the electrons behind it. Electron *A* is urged toward the plate by the hot filament, attracted by the plate, and repelled back by all the electrons between it and the plate. Whether it will move toward the plate or re-enter the filament depends on which of these forces is the greatest.

It is evident that when the electrons in the space becomes so dense that

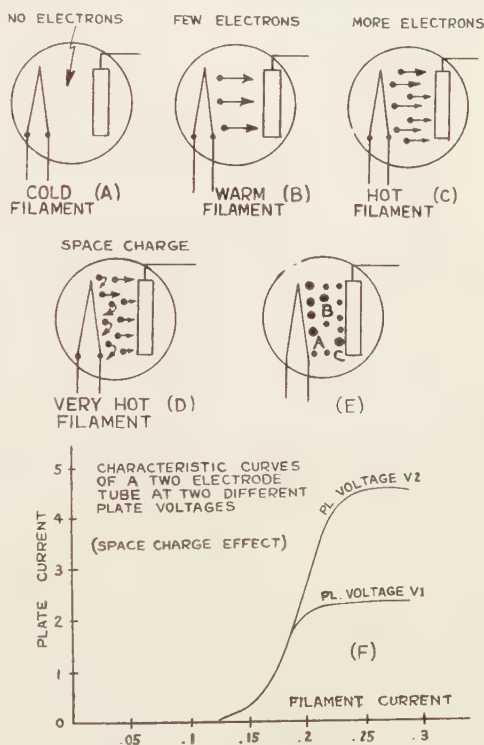


Fig. 44—Space Charge Action

their combined negative charge—"space charge"—is equal to, or greater than, that of the plate, they neutralize the action of the plate and the electron flow to the plate cannot increase even though the temperature of the filament is raised. At this point any additional electrons in the space of the tube makes the space charge overbalance the plate charge and repel the excess emitted electrons back to the filament, as shown in Fig. 43D. In order to increase the plate current at this point, the plate potential must be increased. Thus for every value of plate current, there is a certain value of filament temperature beyond which no increase in plate current can be obtained.

The phenomenon of space charge is illustrated in the graph of Fig. 44F, where filament temperatures are plotted along the horizontal axis and plate currents along the vertical axis. For any given plate potential the plate current increases as the filament temperature rises, up to the point where the space charge becomes predominant, where the curve bends over and becomes horizontal. If the plate voltage is increased to a new value, the plate current curve rises higher before bending over, because it takes a greater space charge to offset the effect of the plate at the higher potential.

65. **RECTIFIER:** The two-electrode tube described above was used in the early days of radio as a detector. When an alternating signal voltage is introduced in the plate circuit instead of the "B" battery, no current flows during the half cycle when the plate is made negative with respect to the filament, since the electrons do not leave the filament on account of the repulsion from the plate; but current does flow when the plate is made positive. Thus only one-half of the alternating current voltage wave is effective in producing a plate current and the tube acts as a rectifier. Vacuum tube rectifiers play an important part in the successful operation of electric receivers, for changing the alternating current obtained from the electric lighting socket to direct current. They will be studied in detail in a later chapter.

66. **THREE-ELECTRODE TUBE:** The main application of the two-electrode tube at present is as a rectifier of alternating current in battery chargers, and power units of "electric" radio receivers.

For amplifying and detecting, it has given way to the three-electrode tube, developed by Dr. Lee DeForest in 1907. This tube is essentially the same as the former, but has in addition a third electrode in the form of a metallic mesh, called the grid, which is interposed between the filament and the plate. Since in the two-electrode tube, with a given filament temperature, the flow of electrons depends on the potential of the plate, if a third electrode, or grid, is inserted between the filament and plate so that the electrons must go through the open spaces in it on their way to the plate, then, by varying the potential of this third electrode the electron flow can be controlled. When it is made positive with respect to the negative ends of the filament, by means of a battery or some other source of potential (Fig. 45B), it tends to neutralize the effect of the space charge, thus permitting more of the electrons to get to the plate, and so increasing the plate current.

When it is made negative (by connecting the negative terminal of the battery to it), Fig. 45C, it assists the space charge in repelling some of the

electrons back to the filament, so fewer electrons get to the plate and the plate current is decreased. When the grid is made positive, it collects a few electrons from itself, acting like a second plate, giving rise to a current in the grid circuit from grid to filament. This should be remembered, as it becomes important in the practical use of the three-electrode tube in modern receiving sets.

67. **AMPLIFYING PROPERTY:** It is evident from the foregoing considerations that the plate current in a three-electrode tube can be controlled by any of three factors, the filament current, the grid potential, and the plate potential. *The grid of the tube, being much closer to the filament than the plate, can, when a potential is applied to it, control the electron emission far more effectively than the same potential applied to the plate.*

Suppose the positive potential grid of a tube is changed by, say, two volts. This would result in a plate current change of, say, four milliamperes. Now, obviously, the plate current could also have been increased the same amount

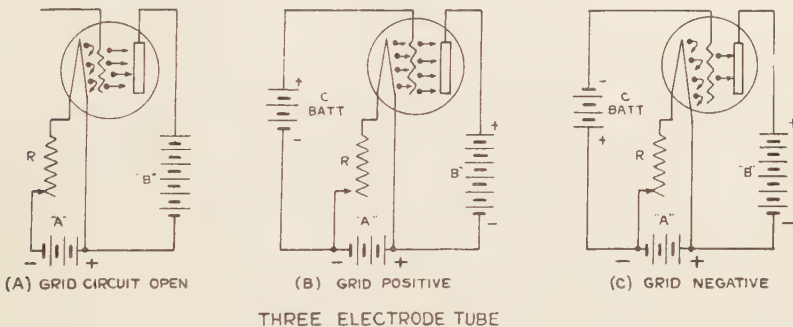


Fig. 45

of four milliamperes by boosting the plate voltage instead of the grid potential. But it takes a considerable increase in plate voltage to affect the plate current to the same extent as that caused by a relatively small increase in grid potential, since the grid is much nearer to the filament than the plate is, and therefore controls the electron flow more effectively. In the standard 201A tube a voltage change in the grid will produce *eight times* as much plate current change as an equal change in voltage on the plate will. For a 224 type tube this ratio is about 400! That is, it requires 400 times the number of volts change in the plate circuit to affect the plate current to the same extent as that accomplished by the grid. That is, the voltage amplification of the 224 tube is 400.

We thus have a sort of trigger action here, a small voltage on the grid controlling the plate current just as effectively as a much larger voltage change on the plate would do it. The relative effects vary inversely as the cubes of the relative distances between the elements in the tube.

In a radio receiving set, we are interested in taking the very weak signal voltages set up in the aerial circuit and amplifying them greatly by making them produce large plate current changes in amplifying tubes arranged in proper circuits. We could make these signal voltages vary the plate currents by applying

them either to the grid circuits or to the plate circuits of the vacuum tubes. But, if the voltages are applied to the grid circuits they will produce much larger changes in plate current (depending upon the amplification factor of the tubes used) than if they were applied to the plate circuits. Hence, since the volume of sound produced by the loud speaker depends on the amplitude of the plate current variations in the last tube, the circuits of all modern receiving sets are arranged so the signal voltages are applied to the grid circuits. This amplifying property of the three-electrode tube is one of its valuable properties.

In Fig. 46 are shown in various parts a UX-201A tube. Looking from left to right we have the plate, grid, mounted filament, three-electrode assembly sealed in a glass tube, and the complete tube. Notice that in the final tube the

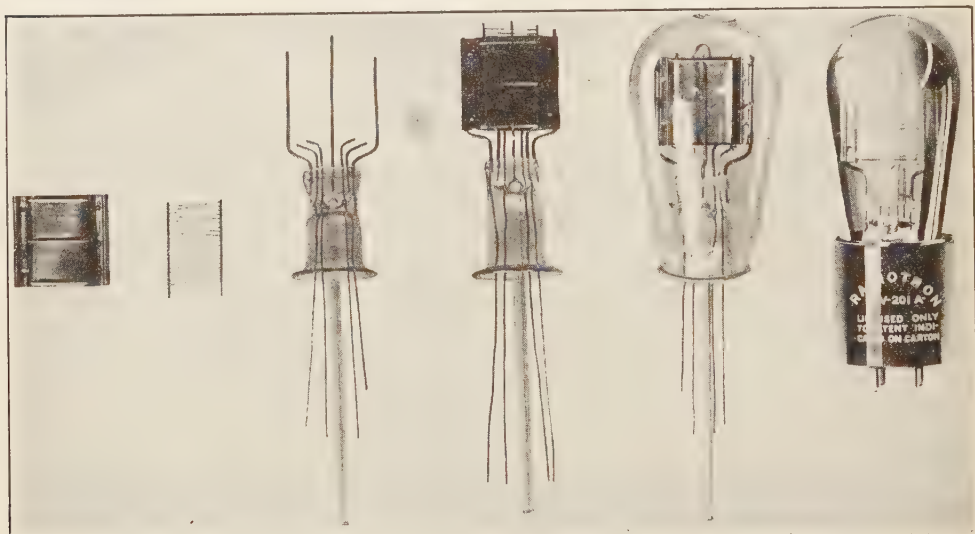


Fig. 46—Assembly Stages of 3 Electrode Tube

V-shaped filament is in the center; around this is the spiral wire grid; and surrounding these is the metal plate.

68. **CHARACTERISTIC CURVES:** The behavior of vacuum tubes is best indicated by curves showing the relation between various factors. The actual change in plate current due to a change in potential on the grid of an ordinary radio detector or amplifier tube is shown in Fig. 47 by the characteristic curve. This can be obtained by measuring with a milliammeter (a sensitive current measuring instrument) the amount of plate current passing when there is a definite voltage on the grid. The curve is important, for it is by reason of the shape of its various portions that the tube is able to perform its many different functions. The use of a "C" battery, Fig. 45, presents a convenient way of placing any desired steady potential on the grid. It can be made stronger or weaker by varying the battery, and can be made positive or negative by reversing the connections of the battery.

The grid voltage can be varied and the plate current measured for each step, the plate voltage and filament current remaining constant. Three curves are given for various plate voltages. At zero grid potential (Point *A* on the curve), the plate current has a definite value. As the grid potential is made more and more negative, the plate current decreases. As it is made more and more positive, the plate current increases. The curve has two distinct bends, one at *B* and one at *C*. These are called the "knees" of the curve.

It is interesting to note that in the region of the negative grid potential, since there is practically no grid current flowing, we have the condition where a mere change of potential on the grid circuit controls the energy in the plate circuit.

In the practical operation of the tube, the temperature of the filament and consequent electron emission must be sufficiently high so that the normal plate and positive grid voltages do not cause saturation of the tube (see Art. 63), for if this happens, the grid cannot control the plate current and the tube becomes inoperative.

69. EFFECT OF GAS IN A VACUUM TUBE:

The foregoing explanations of the actions taking place in the vacuum tube were based on the supposition of a very perfect vacuum in the tube. Under these conditions, the tube operates entirely by the normal, unimpeded electron stream between the filament and plate. If the space in the tube contains more than the slightest trace of gas, and the plate voltage is high, the operation is somewhat more complicated, and a larger plate current will usually flow for a given plate voltage, provided ionization takes place.

The actual rate of emission from the filament is not affected, but the liberated electrons on their way to the plate collide with the atoms of the gas. The electrons in the gas atoms revolve in orbits around the central nucleus and some of these orbits are quite distant, relatively, from the nucleus. Some of these far-out electrons of an atom collide with the emitted electrons from the filament and are carried along to the plate, by the action of the positive charge on the plate. The process of losing electrons from an atom is called ionization, and the part left behind is called an ion. Since the ion has a preponderance of positive charge because it is derived from an atom minus an electron, it moves toward the filament and tends to reduce the negative space charge in the tube. Thus both parts of the disrupted atom contribute to the increased electron and plate current flow through the space. The action of a colliding electron upon an atom is called "ionization by collision," and on account of it, larger plate currents will usually flow with given plate voltages in tubes having a poor vacuum. Air of course is a gas.

Present-day vacuum tubes of the common type are made with a high degree of vacuum so that no appreciable ionization takes place. In some special purpose

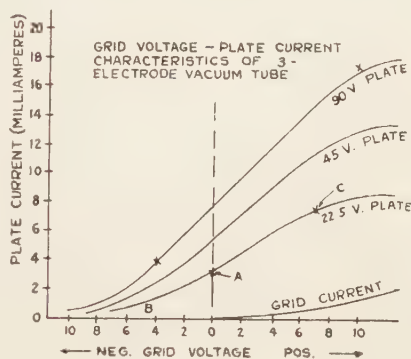


Fig. 47

tubes, as the Donle Sodian detector (now obsolete), a certain amount of ionization was employed to obtain certain desired characteristics.

Ionization in a tube might at first seem desirable, since its effect is to increase the plate current. Actually, however, it is undesirable since it interferes with the normal operation of the tube. Also, since the ions which are driven violently against the negatively charged filament are much more massive than electrons, the bombardment actually seems to tear away the surface of the filament, disintegrating it and reducing its useful life. Ionization in a tube is usually accompanied by a visible blue glow discharge, although a blue glow in a tube may be produced by other actions which are not harmful. The tube usually becomes very erratic in behavior when in this condition. It is not sensitive in a receiver, since the plate current becomes so large due to the ionization that it is practically unaffected by variation of the grid voltage. Some of the old gas-filled detector tubes could be made to ionize strongly at plate voltages as low as 100 volts.

70. HARD AND SOFT TUBES: "Soft" or gassy tubes are particularly useful as detectors. Tubes having a very high degree of vacuum are called "hard" tubes. They generally make the best amplifiers.

Practically all tubes used in modern radio receivers are high vacuum or "hard" tubes. Tube manufacturers employ elaborate machinery and manufacturing operations in a special effort to remove every last trace of air from the inside of the tube during the course of manufacture. The scientific "de-gassing" processes applied to remove even the slight amount of air entrapped in the pores of the metal elements and inside surface of the glass tube are well known examples of this. This is partly due to the effort to produce tubes having longer filament life, and to the practical problem of producing tubes for operation at high plate voltages. These high plate voltages (such as exist in the 245, 210 and 250 type tubes) cause ionization effects which would be absent in tubes designed for lower plate voltages, for a given amount of air or gas present.

Commercial forms of "gassy" tubes are apt to be rather non-uniform on account of the practical difficulties involved in manufacturing tubes of this type on a large scale by quantity production methods, and turning out a high percentage of perfect tubes which are all exact duplicates of each other.

REVIEW QUESTIONS.

1. Explain the "Edison effect."
2. Describe the phenomenon of electron emission.
3. Why must the plate in a vacuum tube be kept relatively cold?
4. Describe the action of the two-electrode vacuum tube.
5. Describe the action of saturation current.
6. Describe space charge.
7. What practical application does the two-electrode tube have at the present time?
8. Describe the action of the three-electrode tube.

9. What is the function of the filament, grid, plate?
10. Describe the process of amplification in a three-electrode tube.
11. Of what use are characteristic curves of vacuum tubes?
12. What is the effect of gas in a vacuum tube?
13. Describe the action of ionization by collision.
14. Describe the construction of a three-electrode vacuum tube.
15. Why are all modern tubes used in receiving sets, of the "hard" type?

CHAPTER 6.

VACUUM TUBE DETECTOR AND AMPLIFIER ACTION.

TWO ELECTRODE DETECTOR — THREE-ELECTRODE DETECTOR — GRID BIAS METHOD
— POWER DETECTORS — GRID CONDENSER METHOD — GRID LEAK AND CON-
DENSER — COMPARISON OF TWO METHODS — GRID RETURN — SOFT DETECTOR
TUBES — ADVANTAGE OF V. T. DETECTION — AMPLIFIER ACTION.

71. TWO-ELECTRODE TUBE DETECTOR: In Fig. 37 (Chapter IV) the use of a crystal detector for broadcast receiving was explained. Its many limitations led to its discard in favor of the vacuum tube detector. The two-electrode tube was used for many years, being known commercially as the Diode tube. The circuit, Fig. 48, was essentially the same as the crystal detector receiving circuit of Fig. 37, except that the two-electrode tube with its filament heating battery was substituted for the crystal detector. At the present time two-electrode tubes find little use except as rectifiers. The three-electrode and four-electrode (screen-grid) tubes have supplanted them entirely for amplification and detection.

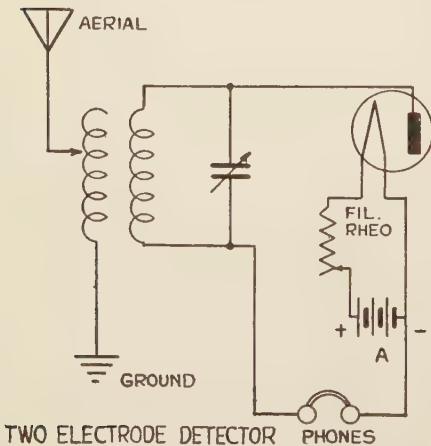


Fig. 48

72. THREE-ELECTRODE DETECTOR: The three-electrode vacuum tube can be made to act as a detector by any one of three main methods. The first is by keeping the average grid potential excessively negative with respect to the filament by means of a "C" battery or other source of potential (having its positive terminal connected to the negative leg of the filament, and its negative terminal connected to the grid circuit). The second method is by maintaining the grid potential excessively positive by means of a battery or other means. The third method is by using a grid condenser and grid leak.

73. GRID BIAS METHOD: The first of these is variously known as the

“power detection,” “plate rectification,” “grid bias,” or “C” battery method, and in the manner in which it is accomplished can be most easily explained by reference to the grid voltage-plate current characteristic curve of the vacuum tube, Fig. 49B. The plate current depends on the difference of potential maintained between the filament and plate. As there is an IR drop between various points in the filament, these different points are at different potentials. Therefore some one point in the filament must be taken as the reference point from which all differences of potential must be measured. It has become almost standard practice to refer all voltages to the negative terminal of the filament as a reference point. Thus, if the grid potential of a vacuum tube whose filament is operated on direct current is considered, it is understood that zero grid potential means the grid return lead is connected to the negative end of the filament.

Consider a three-electrode tube connected in a receiving set as shown in Fig. 49A. The tuning circuit consists of the inductance L_1 , L_2 , and variable condenser C . The filament of the tube is heated by the battery “A” and the plate circuit is energized by the “B” battery, which maintains a positive potential on the plate. The grid is connected to the filament through the inductance and the “C” battery and potentiometer P .

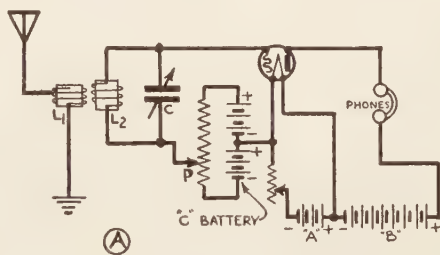


Fig. 49A—Grid Bias Detection

A potentiometer consists of a high resistance which is connected across a battery or other source of e.m.f. One terminal of this resistance is then positive and the other one negative, while at various points across the resistance we find all potentials between these two extremes. If a contact is arranged to slide across the resistance, we can give this sliding contact any desired intermediate potential, and thus if we connect the wire which connects the grid to the filament (grid return lead), to this slider, it is possible to impart any desired potential, within the limit of the “C” battery, to the grid. This imparting of a certain mean potential to the grid of a vacuum tube is called biasing, and we will often revert to biasing or “C” potentials to attain certain advantages in other applications of the vacuum tube. The biasing battery is called a “C” battery.

By sliding the movable contact of the potentiometer of Fig. 49A, it is possible to accurately adjust the grid potential to such a value that when no signal is being received, the operating point of the tube is some point E on the lower bend of the tube characteristic curve of Fig. 49B. Now if a signal is received by the antenna, a high frequency alternating e.m.f. will be set up across the coil and the plates of the condenser C . This is impressed between the grid and filament of the tube, producing at every cycle approximately equal and opposite plus and minus variations ($-A$ and $+A$) of the steady grid potential E . This is represented by the lower curve drawn as a simple wave for sake of simplicity. From the way the characteristic curve bends, it is easy to

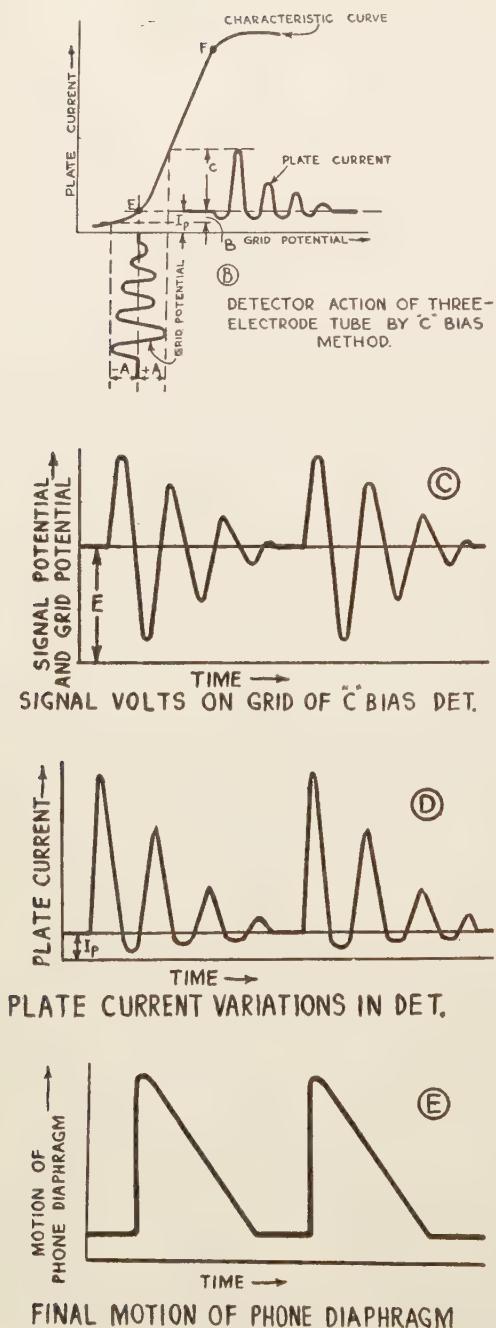


Fig. 49—Grid Bias Detection

see that if the grid potential increases "A" volts + (right) the plate current increases a larger amount (C) than it decreases (B) when the grid potential decreases "A" volts—(left). The "B" variations have been practically eliminated and due to this cutting off of the lower portion of the wave we have rectification and the tube acts as a detector. The sharper the bend of the curve the more perfectly the "B" variations will be eliminated and so the more perfect the detection.

Considering this signal voltage variation, the grid potential, plate current and final motion of the phone diaphragm are shown in Fig. 49C, D, and E. Notice that with this method of detection, the effect of every cycle of the signal voltage is to produce a large increase and a small decrease in the plate current, as shown by the middle curve; and that the resulting movement of the diaphragm follows the wave form or envelope of the received modulated radio frequency potential due to the inertia of the diaphragm and the inductance and capacity of the windings in the phones, as explained in Chapter IV.

It is evident that the operation of the tube about the point *F* on the upper bend of the curve by putting a positive voltage or bias on the grid is similar to that on the lower bend with the exception that at every cycle the incoming signal produces a large decrease and small increase of plate current. However, in practice the operation around the lower bend is preferable and used most since the steady plate current "I" flowing in the plate circuit at all times is much smaller than in the case of the upper bend, so the current drawn from the "B" batteries (or other "B" power supply

unit is not so great and their useful life is lengthened. With the UX-201A type of vacuum tube, the upper bend of the curve occurs at comparatively high positive grid voltages (with ordinary plate voltage of about 45). When using the lower bend and 45 volts on the plate, the negative "C" battery bias voltage necessary for detection is around -4 volts. Another reason for not using the upper bend is that when the grid is made positive a current flows in the grid circuit. This is objectionable, as will be seen later.

With ordinary UX-201A type tubes it is usually possible to eliminate the potentiometer by using a standard $4\frac{1}{2}$ -volt "C" battery which has a tap at each of its three cells. The "C" bias can then be adjusted in steps of 1.5 volts, which is usually sufficiently close.

74. **POWER DETECTORS:** The modern tendency in sensitive receiving sets is toward the use of so-called "power detectors." These usually take the form of "C" bias detectors in which a relatively high plate potential and

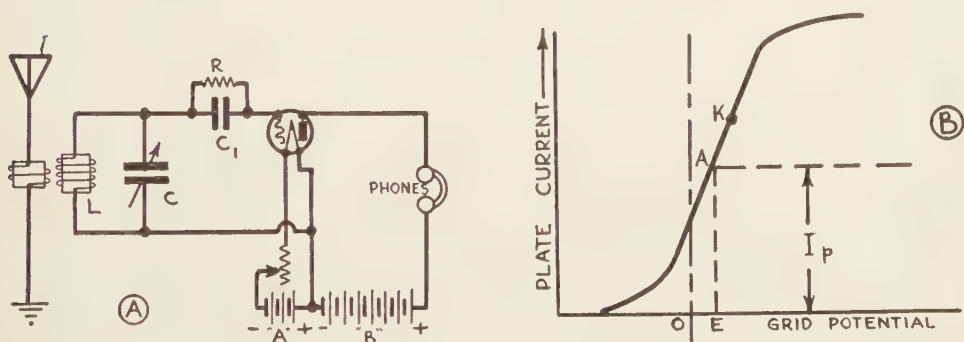


Fig. 50 A, B—Detector Action With Grid Leak and Condenser

negative "C" bias voltage is used on the detector. Detectors of this type are preceded by a large amount of R. F. amplification to cause a relatively large signal voltage to be built up in the grid circuit of the detector. To prevent distortion, the maximum R. F. grid voltage swing must be within the straight portion of the plate current grid-voltage characteristic of the tube. The "power detector" is capable of handling a relatively large signal voltage without distortion. Power detectors will be discussed again in connection with electric receivers.

75. **GRID CONDENSER METHOD:** The grid condenser or grid current rectification method of operating the three-electrode tube as a detector is shown in Fig. 50A. This is based upon the fact that the grid can act more or less in the same manner as the plate and attract electrons itself as soon as it becomes positive with respect to the filament. The circuit is the same as that of Fig. 49A, except that there is no "C" battery in the grid circuit, a condenser "C" is connected in series with the grid, and the grid return is brought to the positive side of the filament. (The detecting action of the ordinary UX-201A type tube is better when a positive grid return is used than when a negative return is employed. This is due to the shape of the grid current—grid potential

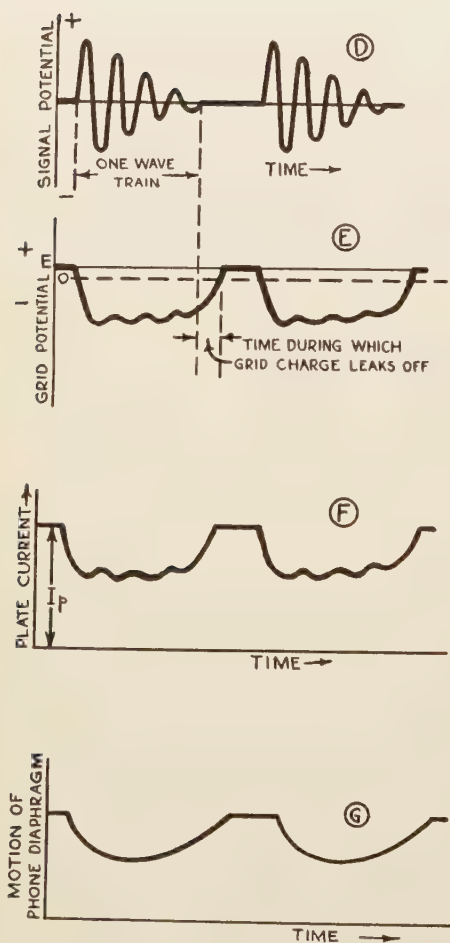
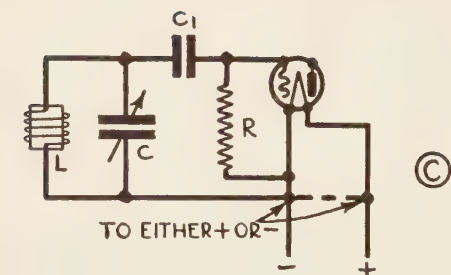


Fig. 50 Cont'd.—Detector Action With Grid Leak and Condenser

curve. Special detector tubes like the UX200A type work best with a negative grid return.)

With this circuit, when no signal is being received, a steady plate current I_p flows from the plate to the filament and back through the phones depending on the voltage of the plate and the temperature of the filament. If the grid return is to the positive side of the filament, the normal grid potential is at E , Fig. 50B, (slightly positive).

When a signal is received by the antenna, an alternating e.m.f. is set up across the coil and the plates of the condenser "C." This alternately charges the grid positively and negatively through the grid condenser "C." During a positive half cycle, the grid attracts some of the electrons from the filament (acting just like a plate). During the next half cycle, when the grid potential becomes negative, the electrons on the grid cannot escape because they are trapped on the insulated part of the circuit comprising the grid and the one plate of the grid condenser. On the next positive half cycle more electrons are attracted to the grid, which are also trapped so they cannot escape from the grid during the succeeding negative half wave. In this way, more and more electrons are trapped on the grid, it builds up a negative potential, and the high frequency potential variations on the grid vary around a mean grid potential which becomes more and more negative, Fig. 50D. This reduces the plate current, and if the grid were perfectly insulated from the rest of the circuit the action, if continued long enough, would finally reduce the plate current to a low value and the tube would be choked or stopped. To prevent this, after a wave train has been received it is necessary to remove the accumulated negative charge from the grid in order

to restore it to the initial condition for the arrival of the next wave train.

If the tube insulation between the grid and filament is not perfect or if there is appreciable gas in the tube (as in soft tubes) the charge will automatically leak off through it. If the tube is well insulated and has a high vacuum, an artificial leakage path must be provided from the grid to the filament. This must be so proportioned that the electrons cannot leak off through the path to any appreciable extent in the extremely short time between a positive and negative wave of the incoming signal, but so the electrons do leak off in the time necessary to complete a wave train, as shown in Fig. 50E.

This can be done by connecting a high resistance R from 1 to 10 megohms (1 megohm equals one million ohms), known as a "grid leak," either across the grid condenser "C" as shown in Fig. 50A, or directly between the grid and the filament as shown in Fig. 50C. The latter method has a special advantage in present-day single control receivers, as we will see later.

The result is that if the incoming signal potential wave is as shown in Fig. 50D, the grid potential follows the variations in its amplitude, Fig. 50E. The plate current varies in the same way, Fig. 50F, and this flowing through the phones energizes the electro-magnets resulting in the final movement of the diaphragm as shown in Fig. 50G. This produces sound waves which are practically a duplicate of those impressed on the carrier wave at the broadcasting station.

76. GRID LEAK AND CONDENSER: With present-day vacuum tubes used for broadcast receiving, a grid condenser of about 0.00025 to 0.0005 mfd. is satisfactory. The best grid leak resistance value is from about 0.5 to 10 megohms, depending on the particular circuit used and reception conditions. In any case it must have a low enough resistance to allow the accumulated negative charge on the grid to leak off during the interval between the wave trains. Its resistance must be high enough to prevent the charge from leaking off the grid too rapidly, in which case there would be only a small change of plate current produced and the signal strength as heard in the phones would be reduced. For receiving comparatively strong signals from nearby broadcasting stations leaks of 0.5 to 3 megohms give best results since they allow the comparatively strong charges to leak off at the proper rate. For weak signals, such as on long distance reception, a tube is much more sensitive if the higher resistance grid leaks are used. In either case, if a grid leak having too high a resistance is used it will result in excessive accumulation of negative charge on the grid, blocking the action of the tube, or making the signals sound mushy. This is usually accompanied by a characteristic "cluck-cluck-cluck" sound in the phones or loud-speakers as the charge leaks off at intervals through the insulation between the tube elements.

High-grade grid leaks having permanent and accurate values of resistance should be used. A grid leak whose resistance varies will cause crackling and frying noises while receiving a program. The resistance element is usually enclosed in a glass tube with metal end-caps for connection and is designed to snap into metal clips furnished on the grid condensers.

A consideration of the theory of condenser reactance and the vacuum tube

shows that for the higher audio frequencies and their harmonics there is considerable by-passing through the grid condenser due to the lowered impedance, and therefore a given signal strength causes less change in grid voltage than at the low frequencies. It is thus important to make the grid condenser as small as possible without offering an appreciable reactance to radio frequency, because if this occurs, the actual radio frequency change in grid voltage will be decreased and therefore the signal volume will be decreased.

Capacities lower than about .0002 mfd. decrease the amplitude of the radio frequency potential impressed on the grid and therefore decrease the signal volume, while higher capacities cause a decrease in output on account of audio frequency by-passing. The best capacity tends to decrease as the frequency increases. Short wave receivers usually employ small grid condensers of the order of .0001 mfd. Broadcast receivers usually employ .00025 mfd. grid condensers.

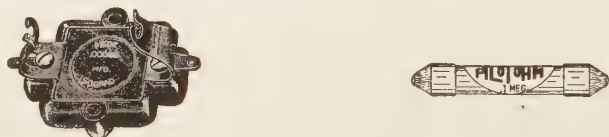


Fig. 51A—Grid Condenser and Grid Leak Resistance

77. COMPARISON OF TWO METHODS: It is important to remember that in the grid leak and condenser method of detection the less the strength of the incoming waves the greater the plate current, and vice versa. In the "C" battery method, using a negative "C" bias voltage, the less the strength of the wave, the less the plate current. The former method is supposed to be the most sensitive because the effects of the little individual wavs of the wave train are accumulative and therefore tend to produce an appreciable change in plate current, and since the tube is operated on the straight portion of its characteristic curve, there is some amplifying action in addition. A disadvantage of this method is the possible frequency distortion due to the varying reactance of the grid leak and condenser with frequency changes. The "C" battery method, while less sensitive, is entirely absent from frequency distortion and is able to handle much greater signal strength without distortion, since it makes the full straight portion of the characteristic curve available. This characteristic makes it particularly suited to present-day radio receivers located near powerful broadcasting station, where great detector sensitivity is not required since multiple stages of tuned radio frequency amplifiers are used, but greater detector signal handling capacity is necessary. In the grid condenser method of detection, the tube operates as a detector at practically any point on its characteristic curve.

78. GRID RETURN: This therefore does away with the necessity of a "C" battery, potentiometer and accompanying adjustments. The curve in Fig. 50B shows that it is to an advantage to work the tube at the center of the curve K, where the greatest slope prevails, so that slight changes in the grid

potential will cause greater variations in the plate current and thus produce the loudest signals in the phones. With the 201A type of tube this is accomplished by connecting the grid return to the positive side of the filament, thus putting a positive grid bias of about 5 volts on the grid.

It should be remembered by referring back to the explanation of the operation of the phones, that it is simply the amount of "change" in the plate current that produces the sound, and not the total amount of current flowing. To produce as large a plate current change as possible it is advisable to either regulate the constant potential of the grid, or shift the curve by varying the plate voltage or the filament temperature. This latter is the reason why it is often found that a detector tube is most sensitive when working at a certain critical filament temperature and "B" battery voltage.

79. SOFT DETECTOR TUBES: Soft detector tubes, i.e., those which contain a small amount of gas, usually are most sensitive as detectors. When a slight amount of gas is present, the electrons emitted by the filament strike the molecules of the gas and break them up into their electrical components, and the gas is said to be ionized, that is, split up into ions. In this state the gas is conductive and a large plate current can be obtained with a low plate voltage. With this low plate voltage the attraction of the plate for the negative electrons is naturally lower and the slightest change in grid potential affects the electron stream considerably. While ordinary soft tubes are the most sensitive as detectors, their use has been hampered by the facts that they are not uniform in characteristics, they produce a hissing noise, and usually the plate voltage and filament temperature must be adjusted critically.

80. ADVANTAGE OF V. T. DETECTION: A very important advantage of the vacuum tube detector over the crystal detector is that while in the crystal detector the signal voltage acts directly across the detector resistance, in the former it acts on the grid and its effect in the plate circuit is therefore multiplied by the amplifying properties of the tube. The signals are amplified at the same time that they are detected. This makes the three-electrode vacuum tube the most sensitive detector we have today.

81. AMPLIFIER ACTION: The three-electrode tube can be used as an amplifier because a small change in voltage applied to the grid produces a large change in the plate current. The extra energy added to the signal by the use of the tube is furnished by the batteries connected to it. The grid really acts like a valve or trigger in the plate circuit. By varying its potential slightly it is possible to control a large amount of energy represented by the plate current in the plate circuit.

Fig. 51A shows the connection of a vacuum tube as an amplifier. This differs from that of a detector mainly in the fact that there is no grid leak or condenser and the steady voltage of the grid is neither at the upper or lower knee of the curve (Fig. 49B), but is preferably kept midway between the two, where the curve is practically straight. Then equal positive and negative waves $+A$ and $-A$ of the grid potential produce equal changes $-B$ and $+C$ of plate current from the normal steady value I_p (Fig. 51B).

This is accomplished by connecting the grid return lead either to the nega-

5. How can "C" bias voltage be obtained?
6. State the advantages and disadvantages of (a) "C" bias detector, (b) grid leak and condenser detector.
7. What are the values of the grid capacity and grid leak resistance most commonly used for broadcast reception?
8. What is a "soft tube"? What advantages do soft tubes possess for detection?
9. Explain the action of the three-electrode tube as an amplifier.
10. Trace the complete path for the filament current in a 201-A tube. Trace the plate current path.

CHAPTER 7.

VACUUM TUBE CHARACTERISTICS.

MODERN TUBES — TUBE CHARACTERISTICS — PLOTTING CURVES — AMPLIFICATION FACTOR — VARIATIONS IN μ — PLATE IMPEDANCE — VARIATIONS IN PLATE IMPEDANCE — MUTUAL CONDUCTANCE — VARIATIONS OF CHARACTERISTICS — POWER TUBES — CHARACTERISTIC CURVES.

82. **MODERN TUBES:** Present-day vacuum tubes operate on the principles discussed in previous chapters. Their design and construction is being constantly refined and practically a perfect vacuum is now being obtained in the millions of tubes being manufactured yearly. Filaments have been improved with a view toward longer useful life and greater efficiency.

Experience has shown that one particular type of tube cannot be used for

all purposes, for best results. There are special tubes for radio frequency amplification, special detectors, and special audio frequency amplifiers of various capacities for handling various amounts of power. We have tubes designed to have their filaments heated by dry batteries, types for use on storage batteries, and the more recent ones which use raw alternating current from the house electric light lines. Though most of them look quite the same externally, they vary in size, shape and spacing of the internal elements, giving rise to different *characteristics*.

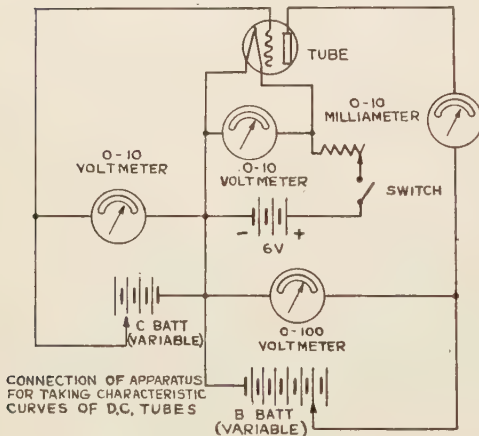


Fig. 52

vacuum tube performance is essential not alone for its general educational value, but also because it tends to promote a better and practical understanding of the theoretical action of the vacuum tube.

84. **PLOTTING CHARACTERISTIC CURVES:** Characteristic curves of ordinary 3-electrode tubes can be compiled from measurements made with the apparatus connected as shown in Fig. 52. A simple laboratory set-up for these tests is shown in Fig. 53. Here the instruments and switches are arranged to

83. **TUBE CHARACTERISTICS:** A knowledge of some of the more commonly used terms regarding

facilitate the work where a great number of tests are to be made. The meters can be of the portable type shown, made either by Weston or Jewell. The chart of Fig. 54 shows the characteristics of various types of tubes commonly used. It will be discussed later.

85. AMPLIFICATION FACTOR: With a fixed value of filament current, the plate current of a three-electrode vacuum tube can be varied either by varying the grid potential or varying the plate potential. However, it can be shown experimentally that a small change in grid potential by a few units (unit equals, say one volt) causes as great a change of plate current as would a much greater change of plate potential. This property is employed in radio receiving sets where the weak incoming signal potentials are applied to the grid circuit and made to produce large changes in plate current, or, in other words, the changes are "amplified". The ratio of the change in plate potential required to vary the plate current a given amount, to the change in grid potential required to produce the same variation in plate current, is called the "Voltage Amplification Factor" or

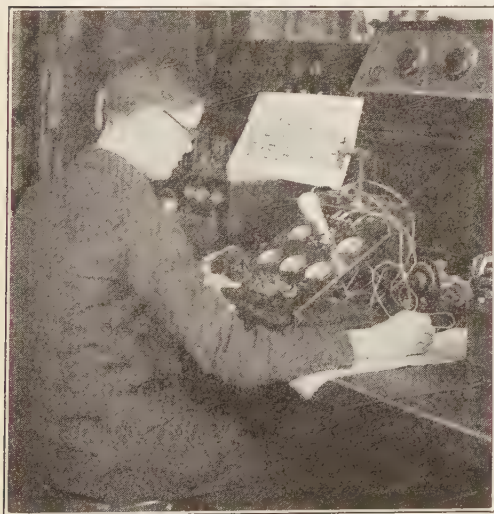


Fig. 53—Laboratory Setup for Taking Tube Characteristics

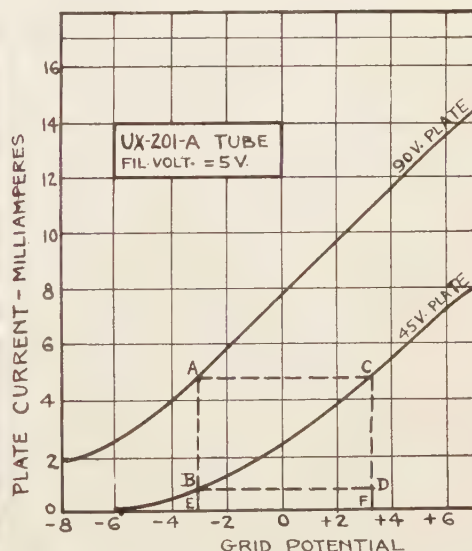


Fig. 55—How Amplification Factor Is Determined

"constant" of the tube, and is commonly designated by the Greek letter μ (Mu).

To show the method employed for finding the amplification factor from the usual characteristic curves of a tube, consider the curves in Fig. 55. These are for a UX-201A tube at plate potentials of 45 volts and 90 volts. Selecting any point B on the straight portion of the 45-volt curve, draw a perpendicular A B E through this point. Draw horizontal lines A C through point A to the 45-volt curve, and B D through B. Drop a perpendicular line from C to F. Now consider

- READY REFERENCE CHART OF VACUUM TUBES -

COMPLETE DATA ON AMPLIFIERS, DETECTORS AND RECTIFIERS

BY ALFRED A. GIRARDI

TYPE	USE	ABAT SUPPLY VOLTS	FILAMENT TERM. CURR. VOLTS AMPS	DETECTION		AMPLIFICATION										CAPACITY BETWEEN ELEMENTS (MMFD.)	TYPE OF FILAMENT	OVERALL DIMENSIONS	
				DET. GRID RETURN LEAK TO	DET. B. VOLTAGE	DET. CURR. (MILLIAMPS)	AMP. B. VOLTS	AMP. NEG. "C" VOLTS	AMP. PLATE CURR. (MA)	PLATE (OHMS)	IMPED. (M HOS)	MUTUAL COEFF.	VOLTAGE FACTOR	OUTPUT (MILLIWATTS) UNDISTORTED	TYPE OF FILAMENT			MAX. DIA. INCHES	MAX. HEIGHT INCHES
WD-11	DET. OR AMPLIF.	DRY CELL 4V	1.1	+F	370-5	22.5-45	1-5	2.5	1.1	12,000	3,000	2.5	2.5	12	OXIDE COATED	6	1	1 1/2	4 1/8
WC-11	DET. OR AMPLIF.	DRY CELL 4V	1.1	+F	370-5	22.5-45	1-5	2.5	1.1	12,000	3,000	2.5	2.5	12	OXIDE COATED	6	1	1 1/2	4 1/8
UX-199	DET.	DRY CELL 4V	3.3	+F	270-9	4-5	1.0	1.5	1.0	12,000	3,000	2.5	2.5	12	THORIATED TUNGSTEN	6	1	1 1/2	3 1/2
CX-299	AMPLIF.	DRY CELL 4V	3.3	+F	270-9	4-5	1.0	1.5	1.0	12,000	3,000	2.5	2.5	12	THORIATED TUNGSTEN	6	1	1 1/2	3 1/2
UX-120	POWER AMP. STAGE 1	DRY CELL 4V	3.3	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-220	STAGE 1	DRY CELL 4V	3.3	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-200A	DET.	STORAGE 6V	5.0	-F	270-3	4-5	1.2	2.0	1.0	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-300A	DET.	STORAGE 6V	5.0	-F	270-3	4-5	1.2	2.0	1.0	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-240	DET. OR AMPLIF.	STORAGE 6V	5.0	+F	270-5	13.5	0.7	1.0	1.0	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-340	AMPLIF.	STORAGE 6V	5.0	+F	270-5	13.5	0.7	1.0	1.0	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-201A	DET.	STORAGE 6V	5.0	+F	270-9	4-5	1.5	1.0	1.0	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-301-A	AMPLIF.	STORAGE 6V	5.0	+F	270-9	4-5	1.5	1.0	1.0	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-222	SCREEN AMPLIF.	DRY CELL 4V	3.3	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-322	AMPLIF.	DRY CELL 4V	3.3	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-226	AMPLIF.	TRANSF. 1.5 V	1.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-326	AMPLIF.	TRANSF. 1.5 V	1.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-227	DET.	TRANSF. 2.5 V	2.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-327	DET.	TRANSF. 2.5 V	2.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-112A	POWER AMP. OR DET.	STORAGE 6V	5.0	+F	370-5	4-5	1.5	1.5	1.0	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-112A	DET.	STORAGE 6V	5.0	+F	370-5	4-5	1.5	1.5	1.0	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-171A	POWER AMPLIF.	STORAGE 6V	5.0	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-371A	AMPLIF.	STORAGE 6V	5.0	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-210	POWER AMPLIF.	TRANSF. 7.5 V	7.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-310	AMPLIF.	TRANSF. 7.5 V	7.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-250	POWER AMPLIF.	TRANSF. 7.5 V	7.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-350	AMPLIF.	TRANSF. 7.5 V	7.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-205A	POWER TUBE STOR. 12V	STORAGE 12V	10.0	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX B52	POWER TRANSMITTER SHORT WAVE STOR. 12V	STORAGE 12V	10.0	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UY 224	POWER TUBE STOR. 2.5 V	STORAGE 2.5 V	1.75	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
C-324	DET. OR AMPLIF.	TRANSF. 2.5 V	2.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
UX-245	POWER AMPLIF.	TRANSF. 2.5 V	2.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8
CX-345	AMPLIF.	TRANSF. 2.5 V	2.5	—	—	—	—	1.5	1.5	15,000	3,000	3.0	3.0	15	THORIATED TUNGSTEN	6	1	1 1/2	4 1/8

~ AVERAGE CHARACTERISTICS OF WESTERN ELECTRIC TUBES ~

"V" VTH	DET-AMP	FORMER-6V	7.6	1.2	+F	0.5 TO 3	12 TO 12	0.5	2.0	1.0	0.2	15,000	18,000	6.5	7.0	890	8000	OXIDE COATED
"E" J55D	DET-AMP	FORMER-6V	4.5	1.6	—	—	—	—	3.0	22.5	35.0	3,500	2,500	2.5	2.4	175	600	OXIDE COATED
"O" 104 D	DET-AMP	FORMER-6V	4.5	1.0	—	—	—	—	1.0	22.5	26.0	2,700	2,100	2.4	2.4	175	600	OXIDE COATED
"L" 216A	AMPLIF.	FORMER-6V	6.0	1.0	—	—	—	—	1.0	26.0	3.0	6,000	4,000	6.0	6.0	60	600	OXIDE COATED
"N" 215A	DET-AMP	FORMER-2V	1.0	0.25	+F	2.0 TO 9	4.5	1.0	4.5	6.0	5.0	2,500	2,000	6.0	6.0	8	40	OXIDE COATED
"V" 102D	RES. AMP	FORMER-2V	2.0	0.97	—	—	—	—	1.30	1.5	0.75	60,000	60,000	30.0	30.0	4.2	50	OXIDE COATED

~ SPECIAL PURPOSE TUBES ~

TYPE	USE	CIRCUIT REQUIREMENTS	PURPOSE	FILAMENT SUPPLY	TERMINAL VOLTS	CURRENT AMPS.	~ CHARACTERISTICS ~	TYPE OF FILAMENT	BASE	MAX. OVERALL DIA.	MAX. OVERALL HEIGHT
UX 280 CX 380	FULL WAVE RECTIFIER	FULL WAVE CIRCUIT	RECTIFICATION IN ELIMINATORS	TRANSF	5.0	2.0	MAX. AC INPUT VOLTAGE PER PLATE (EFFECTIVE) — — — 350V. MAX. DC OUTPUT CURRENT (BOTH PLATES) — — — — — 125MA D.C. OUTPUT VOLTAGE AT MAX. CURRENT AS APPLIED TO TYPICAL FILTER 260V	OXIDE COATED RIBBON	LARGE STD. UX BASE	2 3/16	5 5/8
UX 281 CX 381	HALF OR FULL WAVE RECTIFIER	HALF OR FULL WAVE CIRCUIT	RECTIFICATION IN ELIMINATORS	TRANSF	7.5	1.25	MAX. AC INPUT VOLTAGE PER PLATE (EFFECTIVE) — — — 700V. MAX. DC OUTPUT CURRENT — — — — — — — 85MA D.C. OUTPUT VOLTAGE AT MAX. CURRENT AS APPLIED TO TYPICAL FILTER 620V	OXIDE COATED RIBBON	LARGE STD. UX BASE	2 7/16	1 6/4
RAYTHEON BH	FULL WAVE RECTIFIER	FULL WAVE CIRCUIT	RECTIFICATION IN ELIMINATORS	GASEOUS TYPE (NO FILAMENT)			MAX. AC INPUT VOLTAGE PER PLATE (EFFECTIVE) — — — 300 TO 350 V. MAX. DC OUTPUT CURRENT (BOTH PLATES) — — — — — 125 MA		LARGE STD UX BASE (G PRONG NOT CONNECTED)	1 13/16	4 3/8
UX 874 CX 374	Voltage Regulator	SERIES RESISTANCE	CONSTANT VOLTAGE DEVICE (GLOW TUBE)	DESIGNED TO KEEP OUTPUT VOLTAGE OF B POWER UNITS CONSTANT UNDER DIFFERENT LOADS			OPERATING VOLTAGE — — — 90 V. DC STARTING VOLTAGE — — — 125 V. DC CURRENT — — — 50 MA		LARGE STD. UX BASE	2 3/16	5 5/8
UX 876 CX 376	CURRENT REGULATOR (BALLAST TUBE)	TRANSFORMER PRIM. OF 65V. FOR USE ON 115V. LINE	CONSTANT CURRENT DEVICE	DESIGNED TO KEEP INPUT CURRENT TO POWER OPERATED RECEIVERS CONSTANT DESPITE LINE VOLTAGE FLUCTUATIONS ON 50-75 CYCLE LINES			OPERATING CURRENT — — — 1.7 AMP. MEAN VOLTAGE DROP — — — 50 V PERMISSIBLE VARIATION — — ± 10V.		STANDARD MOGUL TYPE SCREW BASE	2 1/16	8
UX 886 CX 386	CURRENT REGULATOR (BALLAST TUBE)	TRANSFORMER PRIM. OF 65V. FOR USE ON 115V. LINE	CONSTANT CURRENT DEVICE	DESIGNED TO KEEP INPUT CURRENT TO POWER OPERATED RECEIVERS CONSTANT DESPITE LINE VOLTAGE FLUCTUATIONS ON 40-45 CYCLE LINES			OPERATING CURRENT — — — 2.05 AMP. MEAN VOLTAGE DROP — — — 50 V. PERMISSIBLE VARIATION — — ± 10 V.		STANDARD MOGUL TYPE SCREW BASE	2 1/16	8
UX 887 CX 377	PROTECTIVE TUBE	—	CURRENT LIMITING DEVICE	USED IN "B" BATTERY CIRCUITS TO PREVENT EXCESSIVE CURRENT RESULTING FROM SHORT CIRCUIT WHICH MIGHT DAMAGE TUBES OR WIRING			VOLTAGE DROP ACROSS { HALF FIL. 2.5 V. 5.0 AT 20 MA. D.C. ENTIRE FIL. 45.0 90 AT 90 MA. D.C.		DOUBLE CONTACT BAYONET AUTOMOBILE TYPE	7 1/16	1 2 1/2

Fig. 54—Average Characteristics of Vacuum Tubes and Rectifiers

the tube operating at a plate potential of 45 volts and grid potential equivalent to point B on its characteristic curve.

If the grid potential is increased an amount equal to E F (or B D) units, the plate current increases an amount C D. This same increase C D in plate current could also be obtained by keeping the grid potential at E and increasing the plate potential from 45 to 90 volts (point A). Therefore, an increase of E F units of grid potential has the same effect on the plate current as an increase of 45 volts in plate potential. From the foregoing definition of amplification factor, then the μ of this tube is 90 volts minus 45 volts divided by E F (6.3 volts), or $\mu=7.1$. That is, the grid exerts 7.1 times as much influence upon the plate current as does the plate voltage itself at the particular point B on the characteristic.

86. **VARIATIONS IN MU:** The μ is not constant for a given tube, but varies slightly with the plate and grid potentials, as shown in Fig. 56. For

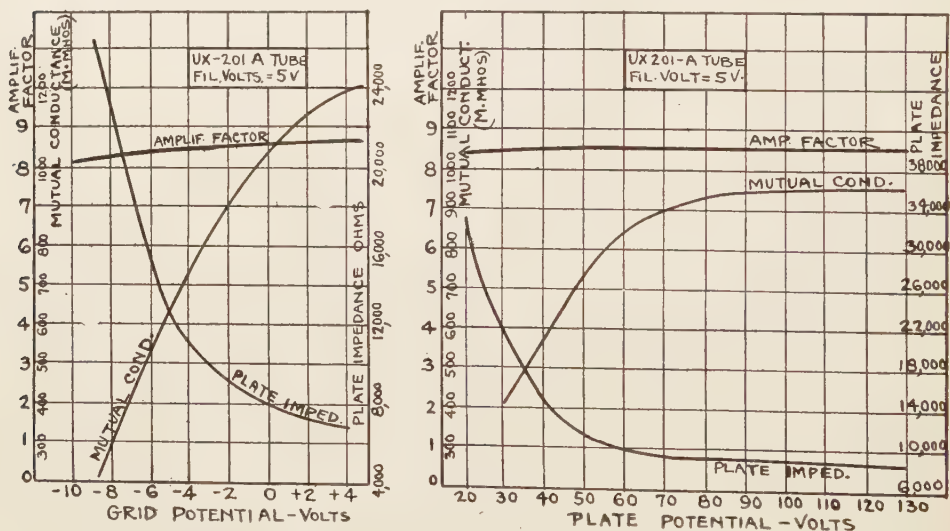


Fig. 56—Various Characteristics of a 201-A Tube

accurate work it is necessary to determine it at the particular values of grid and plate potentials at which the tube is operating, the filament, of course, being operated at the normal current and temperature for which the tube is designed.

The value of an amplifying tube depends, to a large extent, upon its amplification factor. This increases as the grid wires are arranged closer together, making a finer mesh and increasing its effective area, thus giving the grid more control on the plate current; and increases as the ratio between the plate-filament and grid-filament distances increase, since the closer the grid is to the filament the smaller the potential required to set up a field around the filament equivalent to that of the plate. A UX-201A tube has a μ of about 8.5. The UX-240 high μ tube has a value of 30. The UX-224 screen-grid tube has a value of about 400 (see

Fig. 54), although only a fraction of this latter value can be obtained in a practical amplifier. By using very fine-meshed grids mounted at a small distance from the filament, as compared to the distance of the plate to the filament, amplification factors of several hundreds have been obtained in some experimental tubes. It must be remembered, however, that changing the mesh and spacing of the grid and plate also changes other important characteristics of the tube, so that, while high amplification factor might be desired, its attainment may so change these other characteristics that the tube is worthless as a practical amplifier when used in certain positions in a radio receiving set.

Following is a list of the commonly used vacuum tubes, together with their amplification factors at the maximum rated plate voltage:

171A	2.9
120	3.2
245	3.5
250	3.8
WD-11	6.2
WD-12	6.2
201A	8.5
112A	8.2
210	7.7
226	8.2
227	9.0
200A	20.0
240	30.0
222	300.0
224	420.0

Also there are practical mechanical considerations to be taken into account, since if grid and filament or grid and plate are mounted too close together there is danger of them touching together, causing a short circuit; and small mechanical vibrations will produce a proportionately larger change of relative spacing between the elements, resulting in strongly microphonic tubes. For instance, as will be explained later, high μ tubes having a value of 20 or 30 are very valuable for use in resistance and impedance coupled audio amplifiers, but the types available at present are unsuited for transformer-coupled amplifiers because of their high plate impedance, which is about 40,000 ohms, as compared to 12,000 ohms for a 201A type of tube. The screen-grid tube suffers from the same handicap. The vacuum tube data table of Fig. 54 shows the amplification factor, together with other characteristics of standard tubes in use at the present time. The reader should study these carefully, comparing the various characteristics.

87. PLATE IMPEDANCE: When a difference of potential is applied between the plate and filament of a vacuum tube it causes a current to flow through the "B" battery circuit and across the space between the plate and the filament in the tube. The amount of current flowing for a given filament temperature depends not only on the plate voltage, but also on the grid potential. The tube can thus be thought of as a variable resistance, whose value depends on the grid

potential. The lower the grid potential, the higher is the plate circuit resistance, and the higher the grid potential the lower is the plate resistance and the larger the plate current. This is sometimes known as the "internal resistance" of the tube.

Since the plate and the filament in the tube are both made of metal and insulated from each other, they really form a condenser of small capacity, with the filament as one plate, the plate of the tube as the other plate, and the space between as the dielectric. When a varying potential is impressed on the grid, a pulsating current flows in the plate circuit and if the frequency is very high, the small plate-filament capacity cannot be neglected. The tube then acts as a variable resistance equal to the internal plate resistance of the tube, shunted by a condenser having the capacity of the plate to the filament (see Fig. 54 for these capacity values). Their combined effect, for alternating current work, is known as the "plate impedance" R_p of the tube. As the plate-filament capacity is very small (about six micro-microfarads for a 201A type tube; see Tube Characteristic Table), its effect is practically nil except at very high frequencies, and for most tube discussions the internal plate resistance is taken as the plate impedance.

The plate or output impedance is defined as the change in plate potential in volts divided by the change of plate current in amperes which it produces. Using the values ascertained for calculating the amplification constant in Fig. 55, the

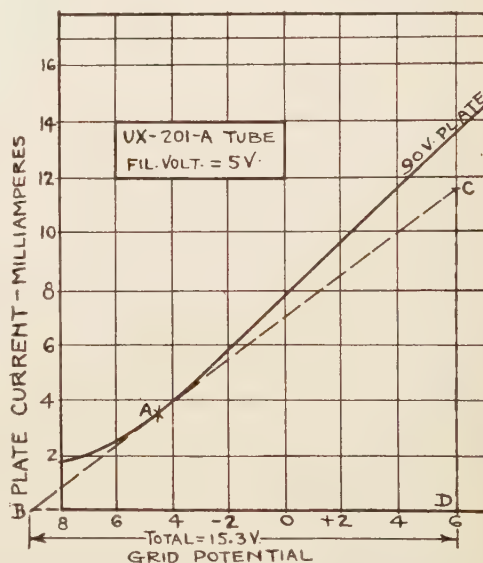
$$\text{plate impedance of the tube is } R_p = \frac{90 - 45}{.004} = 11,250 \text{ ohms.}$$


Fig. 57—Grid-Plate Characteristic of a 201-A Tube

88. **VARIATIONS IN PLATE IMPEDANCE:** As the plate impedance varies (see Figs. 56 and 57) with each change in plate and grid voltage, it should be considered only for small changes and at the point on the characteristic curves where the tube is actually operating in a radio set. The plate impedance depends on the plate-filament spacing and the plate voltage used, the grid voltage, the fineness of the grid mesh, and to a small extent the distance between the grid and plate. The plate must be designed so its temperature is kept relatively low under operating conditions, for if it gets very hot it will emit electrons as does the filament, and hence interfere with the operation of the tube.

89. **MUTUAL CONDUCTANCE:** The essential function of an amplifying tube is to produce a large undistorted change in plate current for a small

change of grid potential. As this important quality of the tube therefore depends upon the ratio of the change in grid voltage to the corresponding change in plate current which it produces, by comparing these values we obtain a figure which is usually known as the "mutual conductance", represented by "Gm". (The conductance of a conductor in "mhos" is defined as the reciprocal of its resistance in ohms.)

The mutual conductance of a three-electrode vacuum tube can be found by taking the amount of "slope" or slant at a point on the characteristic curve. As the curve is not straight, the mutual conductance (slope) changes somewhat for different values of grid potential and plate voltage, so that it should be taken at the point on the curve corresponding to the conditions under which the tube is to work.

In Fig. 57, which shows the plate current-grid potential characteristic curve of a UX-201A tube with 90 volts on the plate, assume that the grid return is connected to a "C" battery of $-4\frac{1}{2}$ volts as is commonly done, thereby setting the normal grid potential at $-4\frac{1}{2}$ volts. The operating point is then point A on the curve. First to take the slope of the curve at this point, lay a straight edge tangent to the curve at the point A, and draw tangent line B C so it cuts the horizontal axis. At any point C draw the perpendicular line C D; now measure the ordinate C D of the point of intersection (say 11.6 milliamperes). Also measure the horizontal distance B D from this latter point to the point where the tangent line intersects the horizontal axis. (Say a total of 15.3 volts.) Dividing the former distance 11.6 M. A. by the latter 15.3 volts, gives the slope of the curve or the mutual conductance at point A, which in this case is 0.76 millimhos. The unit of conductance ordinarily used in vacuum tube work is not the millimho, but the "micro-mho". (Millionths of a mho.) To change to micro-mhos we multiply by 1,000, which gives 760 Mmhos. Figs. 56 and 57 show how the mutual conductance of a tube varies with changes in grid potential and plate voltage.

The mutual conductance can also be found from the relation between amplification constant and plate impedance.

$$\text{Mutual conductance} = \frac{\text{Amplification constant}}{\text{plate impedance}} \text{ or } \text{GM} = \frac{\mu}{R_p}$$

As a general rule, the best type of amplifying tube is one with a high value of mutual conductance. Of course, other considerations, such as filament current consumption, necessary plate voltage, capacity between tube elements, etc., may determine the selection of the type of tube for a given use, but between several tubes, any of which are suitable, the one with the highest value of mutual conductance will be found to be superior for amplification. Fig. 54 gives the values of mutual conductance at various plate and grid potentials for most standing receiving tubes. These should be compared.

90. **VARIATION OF CHARACTERISTICS:** The exact voltages to be used on the plate and filament of a vacuum tube, for best results in a particular radio set, can be determined only by experiment, for it is evident that it is impossible to make duplicate tubes in every respect, although tube manufacturers are doing

marvelously well in this matter. The degree of vacuum to which the tubes are pumped, the sizes and shapes of grids and plates, the distances of each from the filament and from each other, all cause the characteristics to vary slightly from the average values.

91. **POWER TUBES:** It should be remembered that the amplification constant of a tube refers to its voltage amplifying characteristics only; it says nothing about its power handling ability. A tube whose output goes to a loud speaker is called upon to deliver actual electrical power to it, to set the air in motion for the production of sound waves. The plate impedance of such a tube should be kept low so that the power supplied to the plate circuit will not all be wasted in the tube itself. The more voltage it takes, inside the tube, to overcome the plate impedance, the less there is left for use outside of the tube. If the plate load impedance is equal to the plate impedance, the maximum transfer of energy will take place, and as the load impedance becomes less, the energy transfer becomes proportionately smaller, as we shall see later. Usual types of power tubes have a low output impedance and consequently also a low amplification factor. High μ tubes have a very high plate impedance, and are used primarily for resistance and impedance coupled audio amplifiers. The mutual conductance, which expresses both of these factors at once, is a good characteristic to take as a figure of merit of an amplifying tube.

The Radio Manufacturers' Association during its work on standardization in the radio industry has recommended that the expression "Figure of Merit Factor" be used as a measure of the performance of a tube instead of the rather technical term "mutual

conductance" where $FM = \frac{\mu}{R_p}$.

μ is the voltage amplification factor and R_p is the plate impedance of the tube when operated at normal plate and filament voltages. The figure of merit factor obviously considers both characteristics.

92. **CHARACTERISTIC CURVES:** Three electrode tubes are used either as detectors, amplifiers, modulators or oscillators. In each case we are interested in producing changes in the steady plate current by

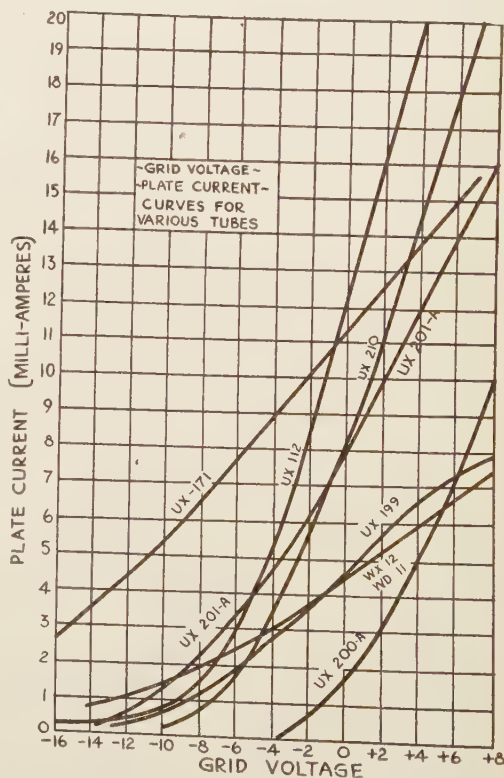


Fig. 58—Grid-Plate Characteristics of Various Tubes

variations in grid potential. The plate current-grid voltage characteristic of the tube is therefore one of the most important.

Fig. 58 shows the relation for various tubes, between grid voltage and plate current, at the same plate voltage, the filament in each case being operated at normal current. The curves are all of the same general form. The current first increases gradually as the grid voltage increases, then more rapidly and finally more and more slowly as saturation is approached. This last condition is met only with high positive grid biases and should not be approached during the normal operation of a receiver.

The slopes of these curves indicate the degree of amplification obtainable, a steep slope indicating a high amplification constant.

REVIEW QUESTIONS.

1. Why are many different types of tubes manufactured? Why is it not practical to use but one type of tube for all purposes?
2. How are the data for tube characteristics obtained?
3. What is meant by the amplification factor (μ) of a tube? Explain just how a tube amplifies a variation in voltage applied to its grid circuit.
4. Upon what factors in the construction of the tube does the " μ " depend? What are the practical construction limits in obtaining high μ in a three-electrode tube?
5. What is meant by the "plate impedance" of a tube?
6. What factors in the construction of the tube affect the plate impedance?
7. What is meant by mutual conductance? What practical use does it play in rating the worth of a tube?
8. What is the function of power tubes? Are their μ and R_p usually high or low?
9. What are the type numbers of three common power tubes? Which one is designed to handle the greatest amount of undistorted power output?
10. What is meant by the "figure of merit factor"?

CHAPTER 8.

VACUUM TUBES IN PRACTICE.

TYPES OF TUBES—CONSTRUCTION—FILAMENTS—ELECTRON EMISSION—THORIATED TUNGSTEN—DESTRUCTION OF THORIUM LAYER—EMISSION TEST—REACTIVATION PROCESS—D. C. REACTIVATION—A. C. REACTIVATION—OXIDE COATED FILAMENTS—OXIDE VS. THORIATED FILAMENTS—GRID AND PLATE—FILAMENT CONTROL—RHEOSTATS—BALLAST RESISTORS.

93. **TYPES OF TUBES:** Vacuum tubes are made in many forms with electrodes of various sizes, shapes and arrangement. The filaments may be designed to be operated from dry cells, storage batteries or raw alternating current. The tubes can be constructed to handle from one to two milliwatts to several thousand milliwatts of power. The filaments may be either of the thoriated tungsten type or coated with the oxides of barium or calcium to increase the electron emission for a given temperature. They may be made in the form of round wires, or flat ribbons; arranged in the form of a straight wire, an inverted V, a double V, etc.

The plates are usually plain, box shaped, or nearly cylindrical, with the grids corresponding. The relative spacing of grid, filament, and plate, as well as the fineness of the mesh in the grid, also varies in the different tubes. Some tubes have been designed with a multiplicity of filaments, grid and plates. In Europe, some tubes have been designed with multiple elements so as to contain within the glass bulb all the necessary parts for one or two amplifier stages. These have not attained great popularity in the United States.

94. **CONSTRUCTION:** Fig. 46 shows the relation of parts and construction of a 201A type vacuum tube. Notice that we have first of all the filament or electron-emitter, surrounded by the grid or controller and this in turn surrounded by the plate. The entire assembly is mounted on a glass flare through which the connecting wires are sealed, and from which a hollow tube extends at the bottom. The flare is then joined to the outside glass bulb, making an upright assembly. The long tube is attached to a vacuum pump and the air is drawn out. To insure a perfect vacuum the tube elements are heated by an induction furnace to release any entrapped bubbles of air from the pores of the metal and the glass surfaces. At this point, a small piece of magnesium (same as ordinary flashlight powder), which has previously been welded on to the plate of the tube (or to a separate little cup), is flashed by raising the temperature by the induction furnace, and the vapor or gas produced enters a vigorous chemical combination with any remaining oxygen

in the tube. The vapor instantly condenses or deposits itself on the inside of the glass bulb and imparts to it the familiar silver-like look or mirror appearance.

The reddish and oil-film effects on some tubes is the resultant of some similar process in which phosphorus as well as magnesium is used.

The presence of the silver coating is thus seen to be merely incidental to the course of manufacture of the tube. The glass stem is then sealed off near the base of the flare. The bulb is mounted in a Bakelite insulating base with prongs for external connection. The prongs are made of hollow brass tubing, and copper lead-in wires from the tube elements run through them and are soldered at the tips. There are two prongs for the filament connections, one for the grid and one for the plate. The later two are smaller in diameter than those of the filament, so that the tube can be inserted only one way in the standard UX

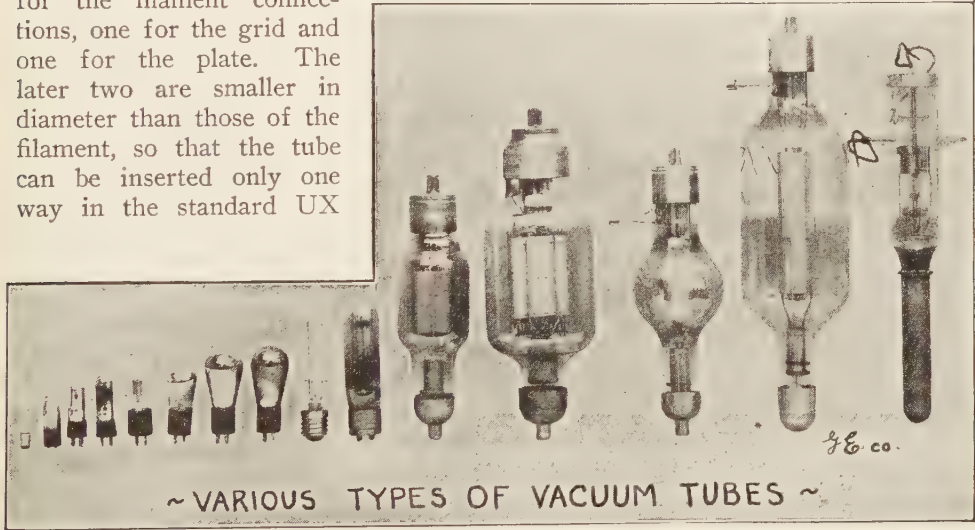


Fig. 59

type socket. This eliminates the possibility of inserting a tube in a socket in the wrong way.

95. FILAMENTS: There are at present three popular classes of vacuum tubes, namely, the dry cell type, the storage battery type and the A.C. type, all deriving their name from the current supply used to heat the filament. A number of commercial forms of tubes are shown in Fig. 59. Those at the left are used in receiving sets, while the large tubes at the right are the powerful tubes used for various purposes in transmitting stations.

Since the function of the filament is to give off electrons, it is evident that it is desirable, in battery operated tubes, at least, to coax out a maximum number of electrons with the minimum filament temperature. By decreasing the necessary temperature of the filament, the amount of electrical power used to heat it is reduced, thus resulting in longer life of batteries, lower operating cost, etc.

96. ELECTRON EMISSION: As explained at the beginning of Chapter V. some substances give off electrons readily at low temperatures while most give

off very few even though heated to extremely high temperature. Among the former are the oxides of the rare metals thorium, barium and calcium.

The electron emission from a large number of materials has been studied and it has been found that a tungsten filament with a layer of thorium on its surface gives about 130,000 times more electrons at a temperature of 1,500 degrees Centigrade absolute than a plain tungsten filament of the same dimensions. Other materials, such as calcium oxide, barium oxide, and strontium, also produce increased emission. Lately the thoriated and oxide coated filaments have been developed, and they are now used almost entirely.

97. **THORIATED TUNGSTEN:** At the present time practically all of the commercial D.C. type tubes use a thoriated tungsten filament (see Fig. 54). This is really a tungsten filament having thorium distributed throughout its mass, and a very thin layer of the metal thorium on its surface. The tungsten serves merely to heat the thorium and to renew the thorium layer as it is used up, the electron emission coming wholly from the thorium layer.

The raw filament wire is made of tungsten impregnated with from one-half to one per cent of thorium oxide and some carbon. (Tungsten is the metal used for the filaments of incandescent lamp bulbs because of its ability to withstand high temperature without melting.)

When such a filament is heated, two important actions take place. As the temperature is increased to about 2,500 degrees Centigrade, some of the thorium oxide is reduced to metallic thorium, and then this gradually works its way to the surface of the filament. At this temperature, the thorium which diffuses to the surface of the filament vaporizes immediately, leaving only pure tungsten at the surface. If the temperature is then lowered to about 1,800 degrees Centigrade for a few minutes, the thorium wanders or diffuses through the filament and when it reaches the surface (provided the vacuum is about perfect) remains there and gradually forms a layer of metallic thorium atoms which never exceeds a single atom in depth. It is this almost inconceivably thin layer which increases the emission over a hundred thousand times. When more thorium atoms work their way to the surface and come up under other thorium atoms already there, the latter at once evaporate, thus maintaining the layer only one atom thick. If the temperature is raised a few hundred degrees the metallic thorium is formed from the oxide more rapidly and comes to the surface more abundantly, but it does not stay on the surface. It evaporates at once, leaving a tungsten surface.

This film is very sensitive and must not be heated to too high a temperature, or it will evaporate. It is necessary to operate such a filament within a narrow range of temperature close to 1,700 degrees Centigrade, where the ratio of evaporation is small and the temperature is high enough for the thorium to diffuse gradually to the surface and continually replenish the layer as it is used up by the normal operation of the tube. In the UX-201A tube this condition obtains approximately when five volts is applied to the filament, sending a current of 0.25 amperes through it.

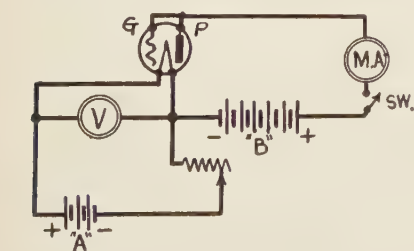
98. **DESTRUCTION OF THORIUM LAYER:** A large proportion of the vacuum tubes used at the present time have thoriated filaments. A list of these is given in the tables of Figs. 54 and 61.

The electron emission of these tubes depends upon the presence of a thin layer of thorium atoms on the outer surface of the filament. During the normal operation of the tubes, the thorium on the outer surface of the filament gradually evaporates. This is constantly replenished by diffusion of the thorium from the inside of the filament. As long as the filament voltage is normal and is not raised over ten per cent above the rated value, the evaporation and replenishing continues at an equilibrium rate so that a constant layer of thorium is maintained on the surface.

If too high a filament voltage is used, the rate of evaporation of thorium is increased more rapidly than the rate of diffusion of the thorium to the surface, the thorium surface layer is partially or totally destroyed, and the emission drops to that of pure tungsten (which is practically zero at these temperatures) and the tube operation is impaired. If the tubes are operated at very low voltages the filament temperature is so low that the process of boiling out the thorium from the interior of the filament becomes abnormally retarded, and the layer is slowly used up.

The great majority of thoriated tubes die a natural death, in that their life continues until all of the thorium in the filament is used up. Obviously nothing further can be done with them. Tubes which decrease in operating efficiency after having suffered some of the abuses mentioned above can usually have their thorium layer and full efficiency restored by the simple process of "reactivation" or "rejuvenation". Reactivation consists of cleaning the surface and reducing some of the thorium oxide in the wire to metallic thorium by heating the filament of the tube (with plate and grid circuit disconnected) to a higher temperature than normal, for a short time, by the application of specified high voltages. This is known as "flashing". Then it is operated for a longer time at a lower temperature. This boils out additional thorium atoms from the interior of the filament and a new active layer is formed on the surface. This is known as "aging". The plate and grid circuits are left disconnected to prevent them from attracting the thorium electrons to themselves during the process.

99. **PRELIMINARY EMISSION TEST:** Before reactivating a suspected tube the condition of its filament should be tested by testing its electron emission to see if it is actually below normal. This is done by connecting the grid and plate together as in Fig. 60, and connecting them to the plus terminal of a "B" battery



CIRCUIT FOR TESTING IF TUBE ELECTRON EMISSION IS BELOW NORMAL

Fig. 60

through a milliammeter of suitable range (see Fig. 61). The remaining connections are shown in Fig. 60. The voltage across the filament, read on V, should first be adjusted to the values specified in Fig. 61, for the particular type tube being tested. This also gives the proper "B" voltage to use. Close the switch *just long enough* to obtain a reading of the emission current on MA. If the reading is less than that specified in the table

the tube can usually be improved by reactivation. If the emission is above the minimum specified, the tube is in good condition, and does not need reactivation.

100. REACTIVATION PROCESS: Reactivation may be done in two ways, depending on the condition of the tube. For a tube which is operating fairly satisfactorily, but which is to be pepped up to maximum, it is only necessary to disconnect all "B" batteries or "B" power unit from the set and keep the tubes lit up at *normal voltages* for two or three hours, using the rheostats on the set to regulate the brilliancy. The storage "A" battery usually used with the set can be employed to supply the filament current. It is very important that the filament voltage be kept exactly at its proper value, as shown by a good voltmeter.

For the bad cases where the tube gives little or no emission, the more elaborate method must be employed. This consists of two steps: first, operating the filament for a very short time at a specified high voltage (called "flashing"), then operating it at specified lower voltages for a longer period (called "aging or cooking"), all of this with grid and plate disconnected. During this process the tube is operated without plate voltage, since under normal conditions with the plate voltage on, the electrons would be attracted to the plate as soon as they are brought to the surface of the filament; but leaving the plate circuit open they are allowed to accumulate on the filament and are therefore available in the required quantities when operation is resumed.

101. DIRECT CURRENT METHOD: Reactivation may be carried on either with direct or alternating current. Fig. 62 shows connections for the direct current method. A is a battery capable of furnishing at least 15 volts. R is a rheostat, GPFF is an ordinary tube socket, and V is a good voltmeter. The resistance R is adjusted until the filament voltage is as shown in the table of Fig. 61, depending on the particular type of tube. It is absolutely necessary that these voltages and times be strictly adhered to, since they are the values found to give best results, after a long series of investigations.

102. ALTERNATING CURRENT METHOD: The alternating current

TYPE OF TUBE	EMISSION TEST			REACTIVATION PROCESS			
	FIL. VOLTS	PLATE VOLTS	MINIMUM EMISSION ALLOWABLE	FLASHING FIL. VOLTS	FLASHING TIME	AGEING FIL. VOLTS	AGEING TIME
WD-11 WX-12 C-11 CX-12	1.1	50	6 M.A.	CANNOT BE REACTIVATED			
UX-199 CX-399	3.3	50	6 M.A.	12	10-15 SEC.	4	30 MIN.
UX-120 CX-320	3.3	50	15 M.A.	12	10-15 SEC.	4	30 MIN.
UX-201A CX-301A	5.0	50	20 M.A.	16	10-15 SEC.	7	30 MIN.
UX-200A CX-300A	5.0	50	14 M.A.	16	10-15 SEC.	7	30 MIN.
UX-240 CX-340	5.0	50	14 M.A.	16	10-15 SEC.	7	30 MIN.
UX-112A CX-112A	EMISSION READING CANNOT BE TAKEN			CANNOT BE REACTIVATED			
UX-171A CX-371A	5.0	50	50 M.A.	CANNOT BE REACTIVATED			
UX-210 CX-310	6.0	100	85 M.A.	NO FLASHING		9	30 MIN.
UX-226 CX-326	1.5	50	35 M.A.	CANNOT BE REACTIVATED			
UX-227 CX-327	2.5	50	35 M.A.	CANNOT BE REACTIVATED			
UX-216B CX-316B	6.0	125	85 M.A.	NO FLASHING		9	30 MIN.
UX-280 CX-380	5.0	80	100 M.A.	CANNOT BE REACTIVATED			
UX-281 CX-381	7.5	150	200 M.A.	CANNOT BE REACTIVATED			
UX-250 CX-350	7.5	250	560 M.A.	CANNOT BE REACTIVATED			

Fig. 61. Emission Test and Reactivation Data

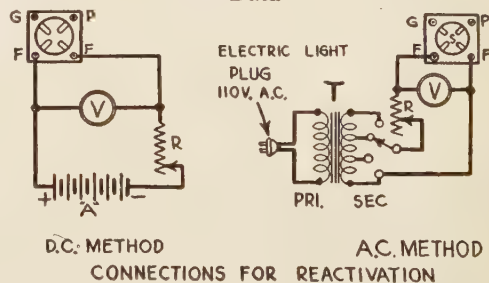


Fig. 62

from the lighting socket can also be used for reactivation. For the alternating current method (Fig. 62) it is necessary to use a step-down transformer T, to step down the 110 volts to that necessary for the test. Any transformer giving the desired voltage can be used. This can be one of the small type used for operating door bells or electric toys. The voltage tap nearest the voltage specified should be selected and a rheostat in series with the filament used to adjust the exact voltage as read by the A. C. voltmeter. The table of Fig. 61 gives the necessary data for those tubes which can be rejuvenated.

A tube can, on the average, be reactivated about six or eight times without any apparent injury to the filament. The emission of various oxide coated tubes can be tested by the process given, but obviously they *cannot* be reactivated, as will be seen presently from a study of this type of filament.

If the tube will not return to normal after proper reactivation treatment, it is proof that the tube has either served its normal life and the supply of thorium in the filament has been used up; or it has been so heavily overloaded that the thorium content has been exhausted or the vacuum impaired. Obviously nothing further can be done with such a tube.

103. OXIDE COATED FILAMENTS: Very early work on vacuum tube filaments showed the value of coating the filament with certain oxides to increase the electron emission. Many of the latest tubes employ oxide coated filaments which operate at a dull red heat (see Fig. 54).

The so-called "oxide coated" filament is usually made with a very thin ribbon of platinum-nickel alloy which serves to conduct the current and heat the electron emitting oxide. Often the ribbon is twisted on itself in such a way as to expose everywhere a sharply curved surface to make the oxide coating stick better. The reader should examine the filaments in some of the larger tubes which use the oxide coating.

A mixture of strontium, barium or calcium carbonate in paraffin is applied to the filament and baked on by heating it to a high temperature for a few seconds. This is repeated several times to build up the coating to the desired thickness. When the filament is mounted in the glass bulb, and the bulb is being exhausted, the filament is lit by a source of current. This high temperature breaks down the carbonate coating and the reaction with the air in the tube forms an oxide and carbon dioxide, the latter being drawn off by the vacuum pump. This oxide coating emits the electrons.

Oxide coated filaments cannot be reactivated, for all of the active material is on the surface of the filament wire and when this is once used up it cannot be replaced. A glance at Fig. 54 will show which tubes use each type of filament.

104. THORIATED FILAMENTS VS. OXIDE COATED: Comparison of the two types of filaments indicates that each has certain advantages. The advantage of the thoriated filament is that if the surface layer of thorium is destroyed it can be renewed by reactivation, as long as there is any more thorium oxide left in the filament wire.

The oxide coated filament has the advantage of being considerably more efficient than the former. The oxide coated platinum-nickel alloy filament uses only about half as much power for the same emission. Also the oxide coated

filament will give the same emission as a thoriated filament when the operating temperature is about 400 degrees lower. If given proper use and care the oxide coated filament has a very long life.

105. **GRID AND PLATE:** The grid of a vacuum tube is usually made of a fine molybdenum ("Moly") wire wound in the form of a flattened spiral around two nickel wire supports, and fastened to them at each turn (see Fig. 46). The plate usually consists of two thin nickel alloy sheets bent and spot welded together, and supported on nickel wire uprights. The plates of power tubes, rectifier tubes, and other large tubes are covered with a carbonized surface layer. This makes them black and aids in increasing the heat dissipation. The reader is advised to inspect the plates on one of these tubes.

The filament is supported at the bottom and top. In some tubes additional bracing to prevent mechanical vibration of the elements is secured by a triangular shaped piece of mica holding the grid, filament and plate supports rigidly at the top. This reduces microphonic noises caused by variation of distance between the elements, with consequent variation in plate current. Nickel is used extensively in radio tubes because it has a high melting point and is readily freed from the "occluded" gases which are present in the pores of all metals and which cause erratic performance of tubes. Molybdenum is also used extensively by some manufacturers for grids and plates.

106. **FILAMENT CONTROL:** Manufacturers of early tubes found it necessary to employ a current control device, in the filament circuit of the tube, so that the tube could be adjusted to its most efficient point of operation. It was not practical to use a six-volt filament energized by a six-volt storage battery because the terminal voltage of the battery decreases as it discharges (Fig. 63), consequently the filament would be burning at its proper temperature only during the short time the battery was fully charged. By designing the filaments for operation on five volts the necessary leeway of one volt was provided. The same applies when using dry batteries for filament supply; the terminal voltage decreases as the battery discharges. The surplus voltage between that required by the filament and that supply by the battery is most conveniently absorbed by a resistance introduced in the filament circuit (Fig. 64A). If this filament rheostat is made variable it can be adjusted at will for best operation at any time.

107. **RHEOSTATS:** A filament control rheostat usually consists of a small coil of special resistance wire (nichrome) arranged in a circular shape so that when a sliding contact passes over it more turns of wire are cut in, or out of the circuit, thus changing the resistance offered to the flow of current; see Fig. 11). Another

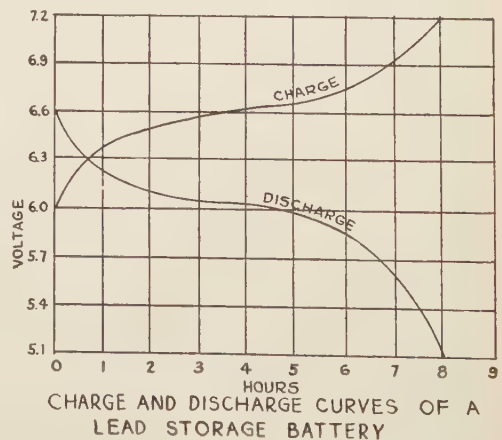


Fig. 63

type of rheostat employs a number of small graphite discs, which when compressed by an adjustable rod, make good contact and offer a low resistance. When the pressure on them is released, the resistance increases. Several rheostats are shown at the left of Fig. 11. Sometimes two or more tubes in a radio set are controlled from the same rheostat as in Fig. 64B. Since the total current is now the sum of the current for each of the tubes, in order to produce the same voltage drop the rheostat resistance must be decreased. The table of Fig. 65 gives the rheostat sizes recommended where one or more tubes are to be controlled from a single rheostat. Resistances of these values give a smooth and wide variation of filament current and make it possible to operate the tubes below rated voltage, either for volume control or some other reason.

Rheostats are made with various maximum resistances, usually 2, 4, 6, 10, 20, 30, 60 and 100 ohms. The rheostats having low resistances are wound with heavier wire and are able to carry more current without excessive heating.

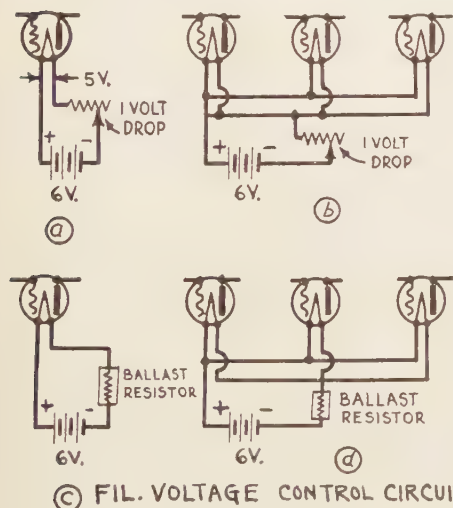


Fig. 64

RHEOSTAT SIZES RECOMMENDED								
NO OF TUBES IN PARALLEL	TYPE OF TUBES	1	2	3	4	5	6	7
		RHEOSTAT RESISTANCE IN OHMS						
112-A	WITH 6V. SUPPLY	20	10	6	6	3	3	2
171-A								
201-A								
171	WITH 6V. SUPPLY	10	6	3	2			
172								
199	WITH 4.5V. SUPPLY	30	20	10	10	6	6	3
199	WITH 6V. SUPPLY	100	60	40	30	25	20	15
120	WITH 4.5V. SUPPLY	20	10	6	6			
222								
120	WITH 6V. SUPPLY	50	30	20	15			
222								
11	WITH 1.5V. SUPPLY	10	6	6	6	3	2	2
12								
11	WITH 2V. SUPPLY	10	10	6	6	6	3	3
12								
VT-2	WITH 6V. SUPPLY	3	2					
216-A								

Fig. 65—Filament Rheostat Sizes Recommended

108. **BALLAST RESISTORS:** The elimination of a multiplicity of controls on receivers is fast becoming popular. It has been found that, in battery operated receivers, most of the rheostats can be supplanted by automatic voltage regulating devices called *filament ballast resistors* (Fig. 11). Their purpose is to automatically regulate the flow of current in a tube circuit and maintain the current value approximately constant over the entire voltage range of the "A" battery between its fully charged and discharged periods. They simplify set wiring and as there are no moving parts, rheostat wires are not noticeable. As the filament is kept at a more constant temperature, the tube life is lengthened. They find special application on amplifying tubes, as detector tubes are more critical in their filament current requirements.

Ballast resistors usually take the form of a piece of iron resistance wire hermetically sealed in a glass tube filled with an inert gas such as hydrogen. The iron resistance wire increases rapidly in resistance with an increase in temperature. Since the amount of current flowing through the wire determines the amount of heat generated, the resistance is self-regulating. If for any reason, more current attempts to pass, the wire becomes hotter and its resistance increases, tending to reduce the current to its correct value. The effect of the gas in the tube is as follows: As the wire tends to get hotter with an increase of current, the gas temperature increases and it becomes a poorer conductor of heat and less heat is conducted from the wire. It therefore tends to make the temperature and resistance of the wire increase more, and so assists the regulating action.

Ballast resistors are made in various sizes, for controlling single tubes of the various types (Fig. 64C) or for controlling a number of tubes (64D). They are made with metal end caps and mount in clips (see Fig. 11).

REVIEW QUESTIONS.

1. What are vacuum tube filaments usually made of? What are the grids and plates made of?
2. Name the parts in a 201-A tube, and tell the function of each.
3. What causes the silver coating on the inside of the glass bulb?
4. What is a thoriated tungsten filament, and what are its advantages?
5. What causes decrease of filament emission in the above type of tube and how can a tube be rejuvenated?
6. How should a tube be tested for emission?
7. What is an oxide coated filament, and what are its advantages?
8. What materials are used for the oxide coatings on these tubes?
9. What is the purpose of a filament rheostat?
10. What is a ballast resistor and how does it work?

CHAPTER 9.

REGENERATION.

REGENERATION—OSCILLATION—SQUEALING—REGENERATION—TICKLER FEEDBACK—
DESIGN OF THREE CIRCUIT TUNER—FIXED TICKLER—RESISTANCE CONTROL—
CONDENSER CONTROL—TUNED PLATE REGENERATION—ADJUSTING AND
TESTING FOR REGENERATION—REGENERATION SHARPENS
TUNING—SUPER-REGENERATION.

109. **REGENERATION:** Fig. 66 shows the simple detector circuit which was discussed in Chapter VI. This will work satisfactorily, but the sensitivity can be improved greatly. The detector tube not only rectifies the incoming voltages impressed across the grid circuit but also amplifies them. Any variation in the grid voltage produces a corresponding variation in the plate current, and hence if one unit of the varying radio current in the plate circuit is fed back to the grid circuit in some way, so as to *increase* the potential change applied to the grid, it will be amplified by the tube again, and a plate current variation several times that amount will be produced in the plate circuit. By this means very weak signal impulses may be built up in strength and the sensitivity and volume of a receiver increased. This reinforcing of the incoming signal by feeding some of the plate energy back to the grid circuit is called *regeneration*, and is the reason for the exceptional sensitivity possessed by many of the one-, two- and three-tube regenerative sets used extensively in the past.

110. **OSCILLATION:** It would seem that this building up of signal strength could be carried on indefinitely by continuous feeding back of energy from plate to grid with consequent re-amplification, but unfortunately there is a definite limit to this. This limit is reached when the tube begins to oscillate.

In the description of regeneration given above, it was stated that energy from the plate circuit is fed back to the grid circuit to strengthen the voltage variations between the grid and filament, this resulting in larger plate current variations. A consideration of the grid potential-plate current characteristic

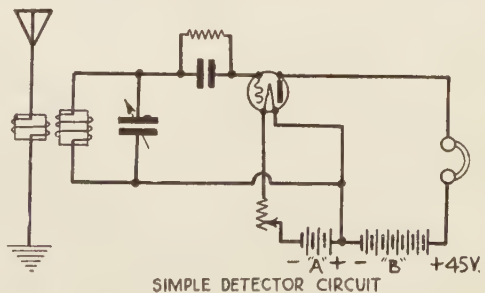


Fig. 66

curve of the three-electrode vacuum tube (Fig. 47) shows that if enough energy is fed back to the grid circuit to more than make up for all resistance losses, etc., this building-up action progresses until the grid potential corresponding to the flat top portion of the curve is reached, at which point a further increase in grid potential no longer causes an increased current flow. At this point, the tube begins to *oscillate*: that is, it converts the direct current energy supplied by the battery into alternating currents of unvarying amplitude of a frequency governed by the frequency to which the grid circuit is tuned. We then have several currents flowing in the receiver. One current is that due to the incoming signal, the second is the local one generated by the oscillating tube, and third current is the combined result of the interaction of these two, which is an audible current, if these two frequencies differ slightly from one another, as will be explained later.

111. **SQUEALING:** Hence when the feedback coupling is set slightly below the value necessary for oscillation, the benefits of the increase in amplification of the signal can be obtained. As the coupling is increased up to just below the oscillating point maximum sensitivity is obtained but the set is unstable, as a sudden momentary increase in grid potential due to a burst of static, or a sudden change in plate voltage or filament emission or any such thing, will set the tube into oscillation. This sudden breaking into oscillation of a regenerative set operating just under the oscillation point is familiar to all owners of regenerative receiving sets.

When the tube oscillates the oscillations may or may not be heard in the earphones. If the set is tuned exactly to the incoming signal then the oscillation current will also be of exactly this frequency and nothing will be heard, since there is no difference of frequency, and this being a radio frequency, it is inaudible. However, as the tube goes into oscillation a definite click or "thud" can be heard in the earphones, sometimes followed by a hiss. If a finger is touched on the grid circuit it changes the tuning and a whistle or shushing sound will be heard.

If the set is not tuned exactly to the incoming signal, a "beat note" or note of a frequency equal to the difference of the frequencies of the two currents is set up, as explained. If this beat note is at a frequency which is within the limits of audibility of the human ear, a shrill whistle or squeal will be heard in the earphones, the pitch of the squeal depending on how much off tune the set is.

In either case, the oscillating receiver is acting as a miniature broadcasting station, since the grid circuit is coupled to the antenna, sending out a radio frequency disturbance at whatever frequency it happens to be tuned to. Any station in the immediate vicinity which is receiving a program on nearly the same wavelength will also receive the disturbance from the oscillating receiver, and the currents combine producing a third current which may be of audible frequency. This is heard as a whistle or squeal. It then becomes a nuisance to owners of all nearby receiving sets. *Regenerative sets should be operated below the oscillation point* at all times, or better still, regenerative sets should not be operated in crowded communities at all unless preceded by a radio frequency amplifier blocking tube as explained later.

Properly controlled regeneration added to a detector produces about the same

sensitivity as a non-regenerative detector with two stages of radio frequency (abbreviated R. F.) amplification. This assumes the use of ordinary 201A type tubes. There are several ways of producing regeneration in a receiving set, and some of the more popular ones will be described.

112. TICKLER FEEDBACK: Probably the most popular method of introducing regeneration is by the *tickler coil* method. The tickler coil, consisting of a few turns of wire, is inserted in the plate circuit of the detector tube, as in Fig. 67A. It is coupled inductively to the grid circuit by placing it near the secondary coil of the R. F. transformer, so that its magnetic field will link and unlink with this secondary and thus induce voltages in it, which, when the winding of the tickler coil is in the right direction, are added to the original signal voltages. This in turn results in a larger variation of plate current, increasing the volume of the signals as heard in the earphones.

A by-pass condenser "C" of .0005 to .001 mfd. is connected as shown to present a low impedance path for the R. F. currents to return to the filament, instead of having to flow through the high impedance of the phones. This results in better feedback action and sometimes better tone quality.

In order to produce regeneration, the plate current must pass through the tickler coil in such a direction that the voltage induced in the grid circuit by it will increase the voltage already impressed on the grid by the signal. Otherwise its effect will be to decrease the voltage on the grid and so reduce the sound in the earphones. If this occurs in a tickler which cannot be rotated, it is merely necessary to reverse the connections of the wires leading to and from the tickler.

113. DESIGN OF THREE CIRCUIT TUNER: The usual tickler coil is mounted on a shaft so it can be rotated and its coupling with the secondary coil varied to control feedback. The illustration of Fig. 68 shows a three circuit tuner and the variable condenser used to tune the secondary. Fig. 67C shows how the signal intensity increases as the coupler of a typical three circuit tuner is rotated for one particular wavelength. First the intensity increases slowly, then it is more pronounced and finally a point is reached where a very small movement makes a big change in the output. This is the critical point just before oscillation starts.

The tickler coil should always be placed at the end of the secondary opposite from the primary as shown in Fig. 67B. It should be as small in diameter as possible (should clear the inside of the secondary tube by one-half inch or more)

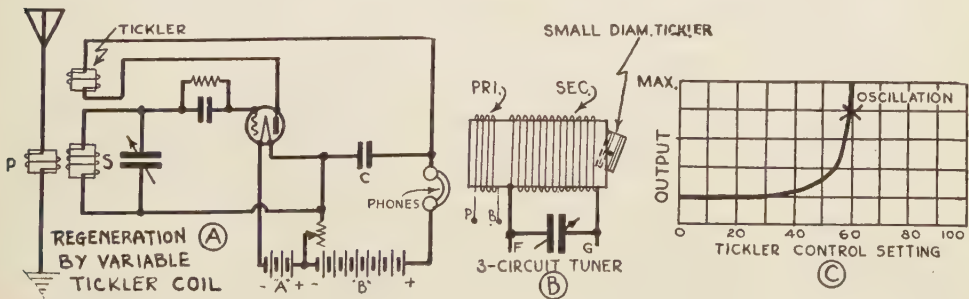
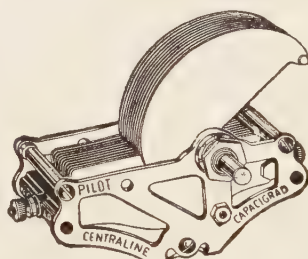
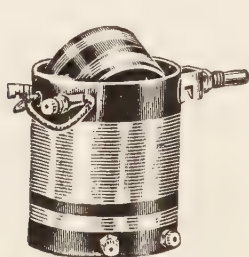


Fig. 67—Regeneration by Variable "Tickler" Coil

so that it will have no appreciable de-tuning effect on the secondary as it is rotated. This also results in smoother control. The tickler can be wound with fine wire, since its resistance is not objectionable. Too many turns should not be used on the tickler because of the de-tuning effect and the sudden "plop" into oscillation. It should have just enough turns to barely make the set oscillate at the highest wavelength of the tuning range when the tickler is turned all the way in.



Illustrations Courtesy Pilot Radio & Tube Corp.

Fig. 68—Left: Three Circuit Tuner. Right: Tuning Condenser

114. FIXED TICKLER-RESISTANCE CONTROL: Another method of regeneration control is by means of a fixed tickler coil wound on the same tube as the primary and secondary coil, but having a variable resistance from 0 to a maximum of about 2,000 ohms shunted across it as in Fig. 69. As the resistance is decreased, more and more of the R. F. current goes through the resistor instead of the tickler and the feedback is decreased. This method gives very smooth regeneration control and has an additional advantage in that there is no rotating tickler to cause variable de-tuning of the secondary and the mechanical construction of the coils is simplified. It also makes possible a more symmetrical layout of the front panel, since the resistor can be placed whenever desired. The resistor used for this purpose should be of high quality and smooth in operation to avoid noisy control. Fig. 70 shows a unit of this type.

Another scheme for resistance control with a fixed tickler is shown in Fig. 71. Here a high variable resistance R of from about 0 to 200,000 ohms is con-

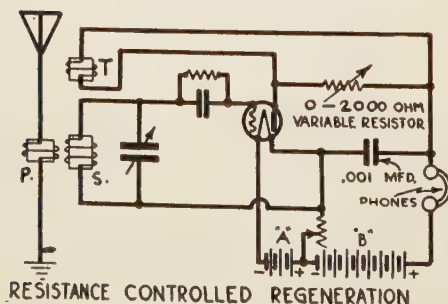


Fig. 69

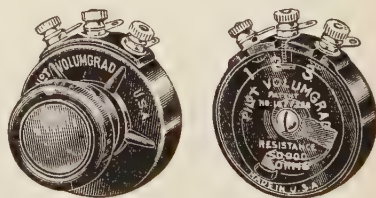


Fig. 70—Front and Back Views of Variable High Resistance for Regeneration Control

connected between the plate and filament. It has a .006 mfd. fixed condenser in series with it to keep the direct current plate voltage off the filament. However, this condenser is of large enough capacity to offer very little opposition to the flow of radio frequency currents. This method also gives very smooth control. The radio frequency choke coil improves the operation by keeping all of the R. F. currents out of the earphones and "B" battery. An easy path is afforded them back to the filament through the .001 mfd. by-pass condenser. The R. F. choke consists of a few hundred turns of fine wire wound on a small spool, and offers a high impedance to the flow of radio frequency currents.

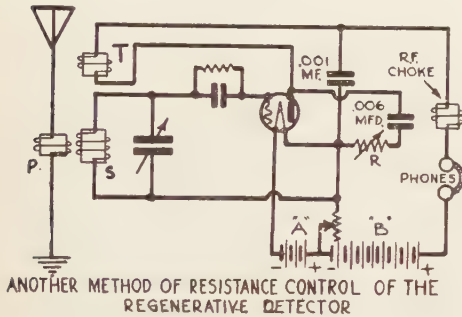


Fig. 71

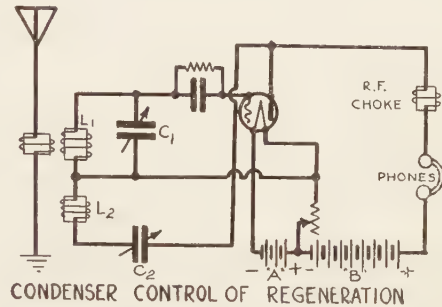


Fig. 72

115. **CONDENSER CONTROL:** Fig. 72 is a diagram of a circuit that employs a fixed tickler L_2 with a variable condenser C_2 for regeneration control. The value of coil L_2 should be from one-half to two-thirds that of coil L_1 , and the condenser C_2 should be approximately of the same maximum capacity as that of C_1 . Here again the R. F. choke coil improves the operation by keeping all of the R. F. currents out of the earphones, and forcing them to flow through the condenser and tickler coil.

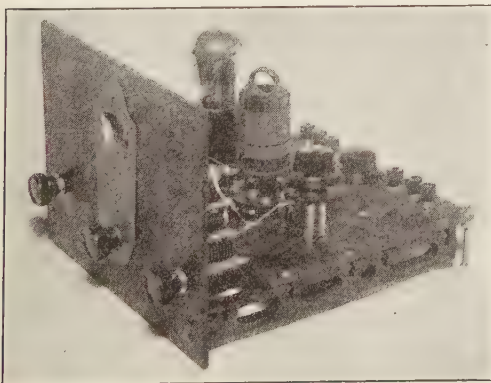


Fig. 72A—Condenser Controlled Regenerative Detector Unit

The variable condenser C_2 serves to regulate the amount of R. F. current flowing from the plate through the tickler coil to the positive side of the filament and back to the "B" battery, and regeneration can be adjusted very accurately over the whole broadcast band. This method of regeneration control is extensively used in short-wave receivers, and here condenser C_2 is usually in the form of the small midget type. (See chapter on Short-Wave Reception.) A simple detector unit of this type is shown in Fig. 72A. This is also some-

times called the "throttling condenser system," or "shunt feed" system.

116. TUNED PLATE REGENERATION: Regeneration with a tuned plate circuit is obtained with the arrangements shown in Figs. 73A and 73B. These methods have been used for a long time. In Fig. 73A the plate circuit is tuned to resonance by a variable inductance L_3 called a variometer. In Fig. 73B, it is tuned to resonance by a coil L_4 with a variable condenser C_4 across it. The coil L_4 and the condenser C_4 should be of the same values in inductance and capacity approximately as L_2 and C_2 . Either method of producing resonance in the plate circuit is satisfactory and results are the same. With this arrangement, feedback takes place by capacitive coupling between the grid and plate of the tube.

When a current of the frequency to which L_4 , C_4 is tuned flows through a tuned circuit of this type, it develops large voltage fluctuations across the tuning units. Therefore, if a signal is being received in this circuit and the plate circuit is tuned to the frequency of this signal, there will be comparatively large voltage fluctuations across the tuned plate circuit and the potential actually existing at the plate will vary accordingly.

We know that the plate, grid and filament are placed concentrically within the vacuum tube and that the lead-in wires and prongs are close together. They therefore form small condensers. As the plate potential varies then, feedback of energy takes place through the capacity existing between the grid and plate (shown by dotted lines in Figs. 73A and 73B). This causes similar fluctuations in the grid potential, and once more these fluctuations are in the same directions as the ones caused by the signal, so the signal is reinforced. The size of the condenser formed by the grid and plate is so small that it is only effective at radio frequencies. The feedback action is sometimes improved by connecting a small variable condenser of about 0.0001 mfd. from grid to plate, especially with tubes having small grid-plate capacity. One disadvantage of the tuned plate system is that the adjustments for regeneration and for tuning are not entirely independent of each other. That is, when the plate tuning is altered, it affects the grid circuit tuning, making it necessary to retune the grid. This has led to the discard of this method in favor of those previously described.

117. ADJUSTING AND TESTING FOR REGENERATION: Regeneration can be employed either with a "C" bias detector or with the usual grid leak and condenser detector. It can also be employed in the R. F. stages, but the control is usually so critical here that it is rarely used. In some cases it will be found that

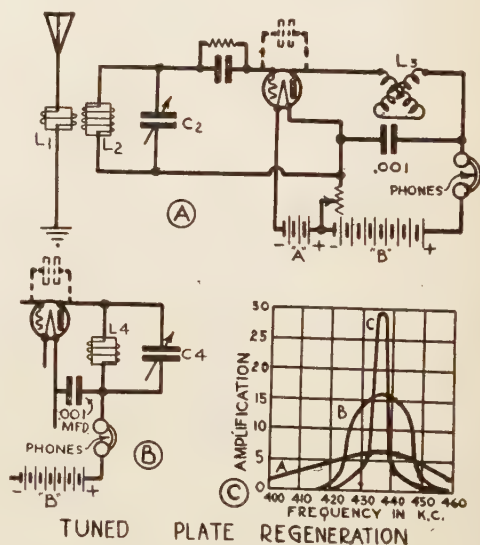


Fig. 73

the receiver has a tendency to go into oscillation with a "plop". This may usually be remedied by adjusting the detector plate voltage or the value of grid leak used. The rotary condenser plates should connect to the filament side of the circuit when possible, to cut down body tuning or capacity effects. In all types of regenerative sets it is necessary to vary the amount of feedback as the tuning is changed in order that the maximum amount of amplification be obtained on the entire band of wavelengths from 200 to 600 meters. The feedback must be increased as the higher wavelengths are received.

It is usually best to control the detector filament (except in the case of A.C. tubes) with a separate rheostat. Often the detector works best at some critical filament temperature, and usually at a lower temperature than the amplifier tubes.

118. **REGENERATION SHARPENS TUNING:** Next to the increased signal strength probably the most important function of a regenerative receiver is to sharpen the tuning. This sharpness of tuning is due to the high amplification of the signal to which the receiver is tuned with only a low amplification of all other frequencies. This is because of the fact that the energy which is fed back is practically all at the frequency to which the receiver is tuned. Thus in Fig. 73C let "A" be the resonance curve of a non-regenerative detector. Notice that the amplification is low and that the circuit is not selective, as it amplifies almost equally over the wavelengths of several 10 kilocycle channels when it is tuned to 437 kilocycles. Curve B, which reaches a peak of over 15, is for a circuit with a moderate amount of regeneration. The amplification of the frequencies below 425 K. C. and above 447 K. C. has decreased. Hence, the selectivity is improved. Curve C, which reaches a peak of 35, represents a detector in which too much regeneration is present. The amplification is very high, but the selectivity is so great that the music is being distorted, since the high frequency notes are cut off, due to cutting sidebands. (This will be explained later in connection with R. F. amplifiers.) This effect is specially noticeable when receiving weak signals with critical regeneration, when the music becomes drummy.

119. **SUPER-REGENERATION:** The super-regenerative circuit developed by Major Armstrong was designed to overcome the limit of amplification present in the ordinary regenerative receiver due to the production of oscillation. It has not become very popular due to several inherent drawbacks, among which are rather poor selectivity, noisy reception due to the tremendous amplification, and complicated adjustment and operation of the set. However, a description of the system will be given here for its technical interest.

It will be remembered that in ordinary regeneration, the limit is reached when the tube starts to oscillate. This oscillation does not reach its final value instantaneously, but requires a definite time (however small) to build up. In this circuit the feedback is first increased so that the current builds up almost to the point of oscillation, the control being so precise that the current builds up to a large amount. Just at the point where the tube would begin to oscillate, the feedback is decreased, the variation in feedback taking place so rapidly that it does not interfere with the signal.

This control of feedback can be obtained in several ways. Either the plate voltage can be varied or the grid voltage can be alternately made positive and then

negative with respect to its normal value, resulting in an increased and then a decreased feedback. It is evident that these variations must be made very rapidly.

The most convenient way of producing these rapid variations in plate voltage or grid voltage is by means of another vacuum tube oscillating at the required frequency, and coupled to the detector tube as shown in Fig. 73. This is a grid voltage variation method.

Tube D acts as a regenerator and detector, having the proper "C" bias on the grid to work it at the bend of the characteristic curve. Tube O acts as an oscillator, generating current at a frequency determined by L_2 and the setting of C_2 .

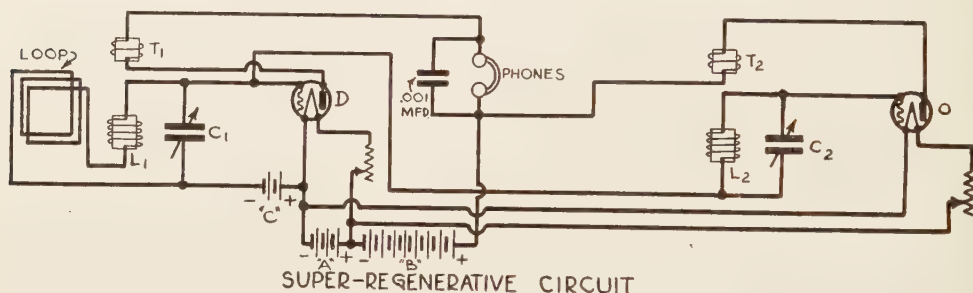


Fig. 74

The signal picked up by the loop antenna is tuned by varying tuning condenser C_1 . Tube D is adjusted so it will cause an increase in the feedback action if its grid voltage is increased in the negative direction. At the instant when the grid of tube O is negative it acts to increase the grid voltage of D in a negative direction since the grids and filaments of the two tubes are in parallel. Likewise when the grid of tube O is positive, the voltage of tube D will be increased in a positive direction. Thus the signal that is present at the instant that the signal voltage begins to increase positively will be amplified until the action is stopped by the decrease in grid voltage due to the oscillation. Obviously, the oscillation impulses must be correctly timed; that is, the frequency of the oscillator must be adjusted accurately. Its frequency must be as low as possible in order that enough time may be allowed for building up the current, yet not so low as to produce noises in the earphones. Many variations of this circuit are possible, one tube can be used as regenerator, oscillator and detector, etc.

REVIEW QUESTIONS.

1. What is meant by regeneration? What is its advantage?
2. What is meant by oscillation? Why can't the building-up action of regeneration be carried on to produce an infinite amount of amplification?
3. What causes squealing in a set when it is oscillating?
4. What is a "beat note" and how is it produced?
5. Describe the tickler feedback method of producing regeneration.
6. How would you remedy the condition of "negative feed back" in a regenerative set?
7. Describe the construction of a three-circuit tuner.
8. Explain the fixed tickler-resistance control method of regeneration. Draw the circuit for this method.
9. Explain the condenser control method of regeneration. Draw the circuit diagram and explain the advantages of this method.
10. Explain the tuned plate method of regeneration.
11. Explain how regeneration sharpens tunings.
12. Explain the principle of super-regeneration.

CHAPTER 10.

RADIO FREQUENCY AMPLIFICATION.

NEED FOR AMPLIFICATION—V. T. AMPLIFIER—RADIO AND AUDIO AMPLIFICATION—
ADDING R. F. STAGES—ACTION OF CIRCUIT—COUPLING TRANSFORMERS—
UNTUNED TRANSFORMERS—TUNED TRANSFORMERS—COMMON BAT-
TERIES—MULTIPLE TUNED R. F.—RESISTANCE COUPLED R. F.
AMPLIFIER—TUNED PLATE R. F. AMPLIFIER.

120. NEED FOR AMPLIFICATION: In Fig. 50 of Chapter 6 a simple receiving circuit was shown (same as Fig. 66). This consisted of a tuning circuit, a vacuum tube detector and earphones. A set of this type gives satisfactory ear-phone operation from powerful broadcasting stations located short distances away. Since the amount of energy decreases very rapidly as the distance from the transmitting station is increased (Chap. 3), it is evident that a simple one-tube set of this type cannot be used for long-distance reception because the infinitesimal currents received in the antenna circuit are not strong enough (even when amplified two or three times by the detector tube), to operate the earphones. Increased sensitivity can be obtained by the use of regeneration, but there is a very definite practical limit to this, as was explained in Art. 110.

The use of earphones has become unpopular, as people desire to hear radio programs in comfort with loud speakers which produce enough volume of sound to be heard clearly at distances of ten feet or more. Loud speakers require a stronger operating current than ordinary earphones do, since they do more work in setting a larger amount of air in motion. It is evident, then, that some energy must be introduced into the receiving set from an outside source in order to achieve this reception; in other words, the received signal energy must be *amplified*.

There is also the consideration that there is a certain definite minimum signal strength, below which the detector will not operate satisfactorily. Consequently, if the signal from a distant station is below this minimum value in strength, it must be amplified before it is impressed on the detector tube.

121. VACUUM TUBE AMPLIFIER: During our study of the vacuum tube we found that it could be used to amplify a change of potential applied between its grid and filament, the amount of amplification produced depending on the type of tube used and the circuit conditions. It is logical, therefore, to use the vacuum tube to amplify the weak signal currents received by the antenna, to make loud reception possible.

122. RADIO AND AUDIO AMPLIFICATION: The idea of using vacuum tubes for amplification opens up two possible methods of application. The high frequency voltage variations existing in the antenna circuit (Fig. 50D) can be amplified before reaching the detector tube, or the lower audio frequency pulsations leaving the detector tube (Fig. 50F) can be amplified before reaching the loud speaker. The former is called *radio frequency amplification*, and the latter is known as *audio frequency amplification*. Each method has advantages and limitations, as will be pointed out later, and the practice in modern receiving sets is to use both methods. That is, the high frequency signal currents are tuned in and amplified by a "radio frequency amplifier", then they are rectified and changed to lower frequency audio currents by the detector, and the audio currents are amplified by an "audio frequency amplifier" before being fed to the loud speaker. A simplified diagram of this system is shown in Fig. 75. The extra energy added to the incoming signal is furnished by the "A" and "B" batteries or other power devices used to operate the tubes in the receiver. The radio frequency (abbreviated R. F.) amplifier will be studied first, reserving the audio frequency amplifier (abbreviated A. F.) for a later chapter.

A tube, together with all the associated apparatus for amplifying purposes, is known as a "stage of amplification". An amplifier consisting of N such tubes is known as an N stage amplifier, etc. The two terminals of the amplifier upon which the incoming signal voltages are impressed are known as the "input" terminals, while the two terminals across which exists the amplified signal voltages are known as the "output" terminals.

123. ADDING R. F. STAGES: A simple vacuum tube detector circuit employing the grid leak method of detection is shown in Fig. 66. This has all of the limitations previously mentioned. We can amplify the R. F. signal currents before they reach the detector by means of a vacuum tube connected as an amplifier. This tube can be connected to the antenna through a tuning circuit as shown in Fig. 76. The problem now is to connect or *couple* this *step* or *stage* of R. F. amplification to the detector, so as to make the varying plate current in the R. F. tube produce corresponding variations of potential on the grid of the detector tube.

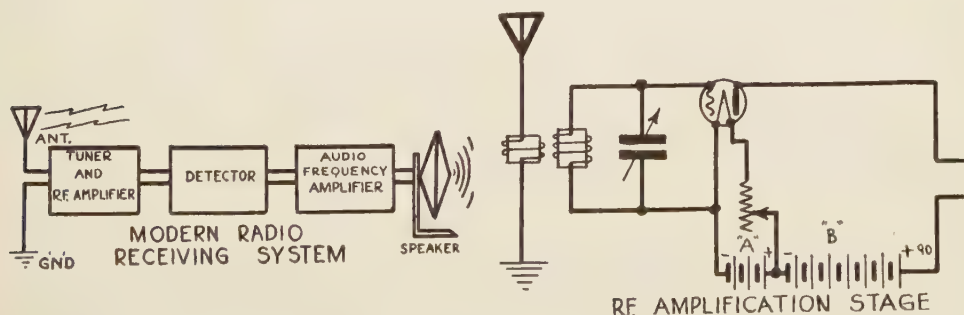


Fig. 75

Fig. 76

The variations in current in one circuit can be made to produce variations of voltage in another circuit by means of a transformer. Therefore, the R. F. stage of Fig. 76 can be coupled to the detector stage of Fig. 66 by means of a transformer T, as in Fig. 77.

124. **ACTION OF CIRCUIT:** Let us stop here for a moment and examine the circuit of Fig. 77 to find out just what happens in each part of it. Very weak R. F. currents are induced in the antenna by the passing electromagnetic and electrostatic waves sent out by the broadcasting stations. The antenna circuit contains a number of these currents received simultaneously from various stations, and all having different frequencies. These currents, flowing through the primary coil A-B of the first transformer, produce magnetic fields which link and unlink with the secondary coil C-D and induce potentials of corresponding frequencies in it. The coil C-D and its associated tuning condenser form a resonant circuit, the resonant frequency of which is determined by the inductances of the coil and the capacity setting of the condenser. The impedance or opposition to the flow of current of this frequency is very small, while the opposition to the flow of currents of all other frequencies is high. Therefore, the induced potential across C-D, which is of this resonant frequency, is able to send an appreciable amount of current at this frequency through the tuned circuit. This current causes corresponding voltage variations between C and D, or between the grid and filament of the amplifying tube (see Fig. 30A). The plate current of the tube flows through the primary E-F of the coupling transformer T. This current is a *pulsating direct current* (because of the rectifying properties of the tube), having pulsations occurring at the frequency of the signal being received and varying in strength according to the modulation (see Fig. 30B). The flow of this pulsating current through the primary E-F of transformer T produces a magnetic field which induces an alternating current in the secondary, of the same frequency as the potential across the grid of the first tube, but of a greater amplitude. The steady flow of the "B" battery current through the primary to the plate has no inducing effect in the transformer, but as soon as it becomes interrupted or pulsating due to the signal, the magnetic field varies accordingly, and a R. F. voltage is induced in the secondary. (This is in accordance with the well known laws of electromagnetic induction.) This voltage acts between the grid leak and condenser terminal and

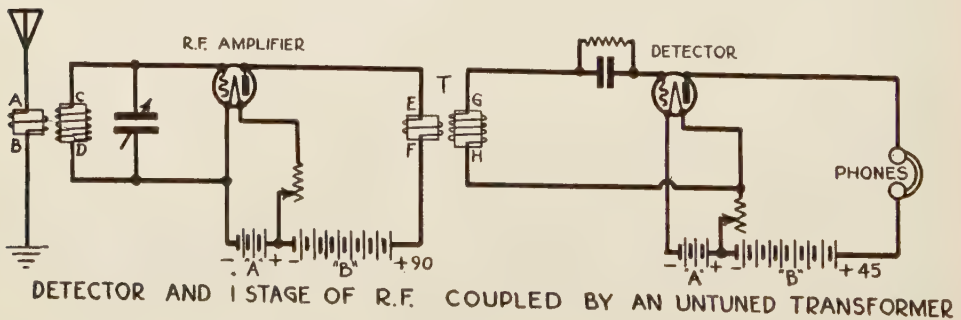


Fig. 77

the filament of the detector tube, producing a pulsating direct current varying at the audio or modulations frequency (Fig. 50F) in the plate circuit and the phones, where the amplified signal is reproduced.

125. **COUPLING TRANSFORMER:** The real use of the coupling transformer "T", then, is to obtain an alternating voltage of radio frequency across the grid circuit of a tube, from the pulsating plate current of the preceding tube. Obviously the higher this input voltage to the grid circuit of the second tube can be made, for a given value of pulsating current in the plate of the first tube, the more efficient the coupling and the louder will be the signals. Usually the transformer is made to give a step-up in voltage by having a greater number of secondary turns than primary turns, although there are other factors which affect this.

126. **UNTUNED TRANSFORMERS:** Fixed untuned transformers of the type shown at "T" were used extensively several years ago, but they have several serious defects. If a receiver is to receive signals from stations over the complete range of the broadcast band from 200 to 600 meters (1,500 K. C. to 500 K. C.), the transformer must be able to efficiently transfer energy from its primary to its secondary at all of these frequencies. It is practically impossible to build a transformer like this. The distributed capacity of the windings, etc., tunes them so that the transformer has a more or less sharply defined resonant frequency at which the transfer of energy is greatest. The transfer of energy can be made fairly constant by using an iron core transformer built up of many thin sheets of soft iron. However, with this construction the high frequency currents set up eddy currents in the core, which dissipate most of the signal energy in the form of heat and very little amplification is secured. Sometimes an arrangement for plugging in different transformers is provided, each set of transformers having a range of about 200 meters. However, this arrangement is more or less of a nuisance when using the receiver in a home where it is enclosed in a cabinet.

127. **TUNED TRANSFORMER:** Much more efficient transfer of energy can be obtained by an air-core transformer having a secondary tuned to resonance by a variable condenser. The condenser can be varied to bring the circuit into resonance at the frequency of the station it is desired to receive. Thus a larger voltage step-up is obtained and the set is made more selective.

128. COMMON BATTERIES:

In Fig. 77 each tube is operated by its own set of "A" and "B" batteries. This is unnecessary, as the two filaments can be connected in parallel across one "A" battery, and both plate circuits can be connected in parallel across one "B" battery. The 45-volt potential for the detector is obtained by tapping off on the 90-volt "B" battery. Fig. 78 shows the connections when this is done. A tuned transformer "T" is used to couple the stages.

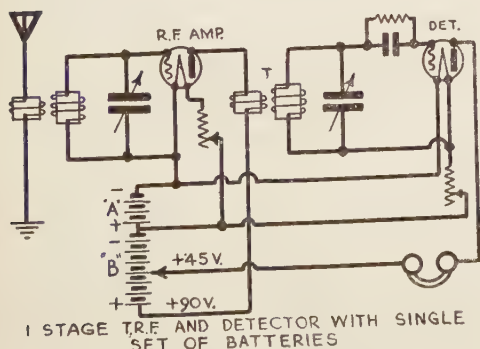


Fig. 78

129. **MULTIPLE TUNED R. F.:** If still greater sensitivity is desired, another stage of R. F. amplification can be added to Fig. 78. This is shown in Fig. 79. Theoretically any number of stages of amplification can be used, but four or five seem to be the limits for practical reception, due to oscillation, etc., which will be discussed later. The popular five-tube tuned radio frequency receiver employs two stages of R.F. amplification.

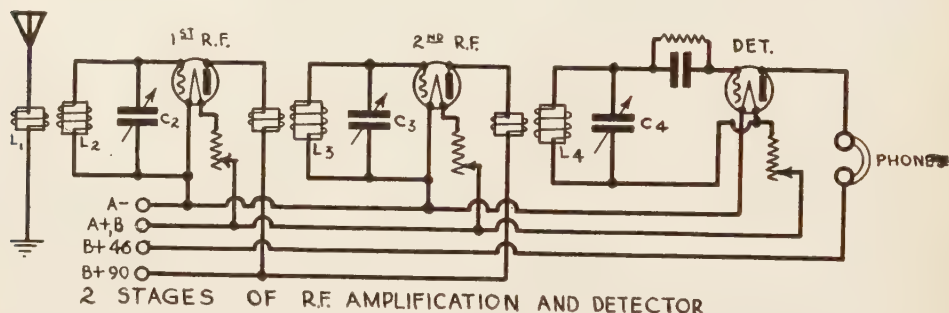


Fig. 79

130. **RESISTANCE COUPLED R. F. AMPLIFIER:** R. F. amplifier stages can be coupled by resistances as shown in Fig. 80. Here the variation of the plate current in the plate resistor R1 produces across it a varying voltage drop which actuates the grid of the next amplifying tube. It is necessary to introduce a blocking condenser "C" to prevent the high plate voltage of each tube from being impressed on the grid of the following tube. The grid is returned through the grid resistor R2 to the negative side of the filament or to the negative terminal of a "C" battery for "C" bias.

This type of amplifier is generally unsatisfactory on broadcast wavelengths of 200 to 600 meters because of the capacity which exists between the plate and filament, grid and filament, and plate and grid of the vacuum tubes employed. At the high frequencies encountered, the low opposition offered by these capacity paths to current flow cause the resistances to be non-effective. The plate filament capacity shunts the resistor R1, acting as a by-pass to the radio frequency currents. The grid filament capacity shunts the resistor R2. The grid-plate capacity produces feedback or regenerative action as well (unless screen-grid tubes are used), as will be shown later.

This type of R. F. amplifier gives splendid results on long wave reception at around 1,000 meters or more. At these comparatively low frequencies the tube capacities are not objectionable. However, all of the amplification in a resistance coupled amplifier is derived from the tubes themselves, no amplification being

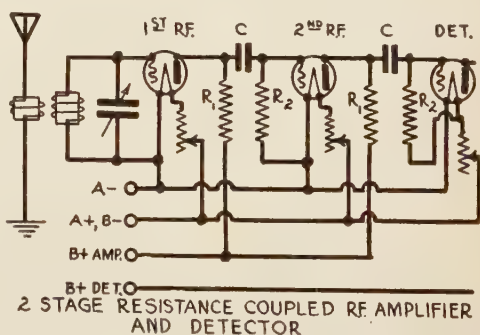


Fig. 80

obtained from the coupling device. This makes it necessary to employ a larger number of tubes for a given amount of amplification than when transformer coupling is used.

The resistance coupled amplifier is especially useful where it is desired to amplify signals over a very wide range of frequencies without changing any of the apparatus in the circuits. An amplifier of this type can be designed to amplify signals from about 1,000 meters to 20,000 meters without changing the parts in any way.

131. **TUNED PLATE IMPEDANCE R. F. AMPLIFIER:** A circuit diagram for a tuned plate inductance or impedance coupled R. F. amplifier is shown in Fig. 81. Each stage contains a plate circuit inductance L and capacity C , which are tuned to the desired wavelength to increase selectivity and amplification (although here again all amplification is produced by the tube itself). Due to the high impedance of the tuned circuit, the resultant voltage variations across it due to the varying plate current are impressed through the blocking condenser C to the grid circuit of the following tube. The usual grid leak resistor R_2 is used in each grid circuit.

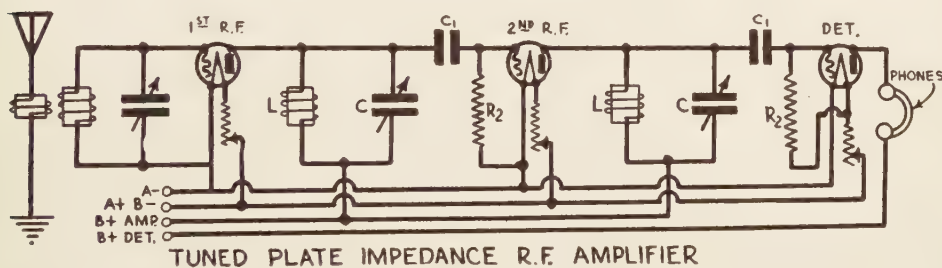


Fig. 81

A serious disadvantage of this method of coupling is that there is a strong tendency to oscillate, due to feedback through the grid-plate capacity of the vacuum tube when the plate circuit is tuned to resonance (unless screen-grid tubes are employed). This tendency is especially strong in multistage amplifiers. It can be reduced by various stabilizing methods, but these reduce the obtainable amplification. This type of coupling, however, can be used to good advantage with tubes having low inter-electrode capacity, such as the screen-grid tube, which will be described in a later chapter.

In some cases this method of coupling is used with a variometer or variable inductance in the plate circuit to tune it to resonance. This consists of two coils of wire of which one, the rotor, can be rotated within the other one, thus changing the direction of its magnetic field, and the total inductance, making it continuously variable.

The tuned plate circuit has an advantage over the resistance coupled R. F. amplifier in that the plate inductance coil offers but little opposition to the flow of the direct current through the plate circuit and hence the "B" battery may be of

lower voltage (for a given effective plate voltage) than if resistance coupling were used. This is because there is a voltage drop in the plate coupling unit which is equal to the direct plate current in amperes multiplied by the resistance.

REVIEW QUESTIONS.

1. What is radio frequency amplification, and why is it necessary in the modern receiver?
2. What is audio amplification?
3. What device is commonly used to couple the plate circuit of one tube to the grid circuit of another?
4. Explain the action of a single stage of R.F. amplification connected ahead of a detector.
5. What are the advantages of using a tuned transformer?
6. Explain the operation of the resistance coupled R.F. amplifier.
7. Explain the operation of the tuned plate impedance R.F. amplifier.
8. What causes oscillation in a multi-stage R.F. amplifier?

CHAPTER 11.

OSCILLATION CONTROL IN R. F. AMPLIFIERS.

PRACTICAL TUNED R. F. AMPLIFIER—STUDY OF T. R. F. AMPLIFIER—FEEDBACK—STABILIZING METHODS—BRIDGE CIRCUITS—WHEATSTONE BRIDGE—RICE CIRCUIT—R. F. L. CIRCUIT—NEUTRODYNE CIRCUIT—SUPERDYNE CIRCUIT—LOSSER METHODS—POTENTIOMETER METHOD—PLATE RESISTANCE METHOD—FILAMENT CONTROL—LOSSER RESISTANCES—TUNED ABSORPTION—EDDY CURRENT ABSORPTION—PHASATROL—CHOICE OF METHODS.

132. **PRACTICAL TUNED R. F. AMPLIFIER:** The tuned R. F. amplifier is probably the most popular type at the present time. Of course, there are many variations of the fundamental circuit of Fig. 76, made necessary by the practical difficulties encountered in making a multi-stage amplifier of this simple design operate satisfactorily because of the inter-electrode capacity existing in the three electrode tube (unless screen-grid tubes are employed). A detailed study of the T. R. F. amplifier will now be made, bringing to light many of these peculiarities and the methods used to overcome them. They are of prime importance at the present time when tuned R. F. sets are so universally used.

133. **DETAILED STUDY OF R. F. AMPLIFIER STAGE:** Fig. 82 is a diagram of a typical R. F. amplifier stage. L2C2 is the tuned input to the amplifier tube, L3 is the primary and L4 the secondary of the coupling transformer, which, when tuned by condenser C4, impresses a voltage E4 on the grid-filament circuit of the following tube. The small series voltage impressed on the input of the first stage, represented by "e," is impressed magnetically through mutual induction from the primary coil L₁. The circuit L2C2 is tuned to resonance with the frequency of this input voltage "e," and when in this condition presents the minimum impedance to the flow of current circulating, indicated by the arrows in the L2C2 circuit. The strength of this current at resonance (see Article 30 Chapter 2) is determined by Ohm's law and is therefore equal to the impressed signal voltage divided by the resistance of the tuned circuit, or e/R . This current in circulating through the inductance L2, builds up a voltage E2 across the L2C2 circuit, which is the A. C. grid potential of the tube, and controls the electron flow of the tube. (The voltage E2 is usually much larger than "e," depending on the size of the inductance L2 and its resistance). This important fact will be discussed later.

This gives rise to a varying plate current which is of the same frequency and character as that in the grid circuit but of greater magnitude. The current flows through the primary of the transformer L_3 , which transfers energy to its secondary circuit L_4 by electromagnetic induction, giving rise to voltage E_4 of the same frequency as E_2 but of greater magnitude. This is fed into the following tube, etc. Since the action in each of the stages in a multi-stage amplifier is similar, we will consider only one stage. The ratio of E_2 to E_1 is called the voltage "gain per stage" and may be any value between about 2 and 20 (with ordinary tubes) depending upon the efficiency of the design. With screen-grid tubes and properly designed apparatus it is possible to obtain even more gain than this.

134. FEEDBACK IN T. R. F. AMPLIFIER STAGE: C_T is the capacity existing between the plate and grid of the three electrode tube increased by the unavoidable capacity existing between the wiring and other metal parts, such as tube prongs, socket contact springs, etc., connected to the grid and plate.

The varying current circulating in the plate coil L_3 gives rise to a varying inductive voltage across this coil. That is, there is an alternating potential difference produced between the plate and filament. This tends to cause currents to flow from plate to filament (since the plate is positive) by every possible path. One such path is from the plate through the grid circuit. This current flowing through the impedance of the grid circuit produces an alternating potential difference between grid and filament. If the grid and plate circuits are both inductively reactive, these alternating potential differences are of the proper phase relation to reinforce the signal potential E_2 and feedback takes place. This is the same action as that taking place in a tuned plate regenerative receiver.

A limited amount of this feedback is beneficial from the standpoint of signal strength since it increases it. However, it may be sufficient to cause the tube to go into oscillation, depending on the characteristics of the tubes used, design of the various tuned circuits, etc., thereby spoiling reception. Since the impedance of any condenser varies inversely as the frequency, at the higher frequencies the impedance of C_T is lower and more feedback takes place. This explains the instability of many T. R. F. sets on the low wave lengths below 300 meters.

The function of the common stabilizing devices introduced in commercial T. R. F. amplifiers is not necessarily to completely eliminate all of the effects of capacity coupling through C_T , for this would reduce the sensitivity of the set materially, necessitating the use of a greater number of stages with increased cost. Rather, the ultimate aim is to control this feedback or regeneration so that an amplifier made up of a number of stages like that of Fig. 82 can be operated just below the oscillation point, but still be rendered stable and easy to tune without producing oscillation. Most of the popular sets on the market today contain two or three R. F. amplifying stages with low resistance, tuned coupling transformers.

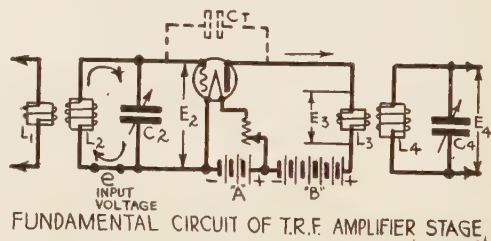


Fig. 82

the main difference between sets of different makes being in the methods used to limit the feedback itself (or the effects of the feedback) through the fixed C_T elements of the separate stages for all tuning adjustments. It may be stated here that the different methods to be described vary greatly in their effectiveness as judged from the ideal action described above.

135. **STABILIZING METHODS:** The methods of feedback control employed fall into three general classes.

A. Neutralization of the feedback through the tube capacity in any of several ways (bridge circuits).

B. Absorption of the feedback energy by deliberate introduction of losses into either the input or output circuits of the tubes (losser methods).

C. Changing the phase of E_3 so it can neither reinforce or detract from the grid voltage (plate stabilization).

136. **BRIDGE CIRCUITS:** Strictly speaking a bridge circuit is one which is independent of frequency. The principle employed is the following property of an alternating current.

137. **WHEATSTONE BRIDGE:** If a bridge be arranged with four arms (which may be capacities, inductances, or resistances) and the bridge is properly balanced, then an alternating voltage impressed between either pair of opposite points of the bridge can produce no voltage drop between the other pair of opposite points on the bridge. That is, a balanced bridge is a circuit in which two spaced points are electrically isolated from two other points.

The practical application of this is to connect a small condenser in such a way that the current flowing through it affects the grid to an extent just equal but exactly opposite to the effect of the current flowing through the grid-plate capacity.

138. **RICE CIRCUIT:** Fig. 83A shows one form of bridge circuit known as the Rice circuit. A small variable neutralizing condenser NC is connected from the plate to the lower end of the tuning circuit. If L_2 and L_5 are inductively equal (center tapped coil) and NC equals the plate-grid capacity of the tube, the

bridge is balanced and the balancing of the current through NC against the feedback current of C_T is independent of the frequency. The circuit cannot be over-neutralized for on either side of the value of capacity of NC required for balance, the tube resumes oscillation. Thus, once it is neutralized at all, it will be neutralized for all frequencies. One difficulty which arises in applying this system in a receiver is that neither side of the tuning condenser C_2 is at filament potential. This necessitates the use of a condenser with an insulated rotor shaft or a tandem condenser, part across each half of the L_2 - L_5 combination, as shown in Fig. 83B. This is necessary in order to

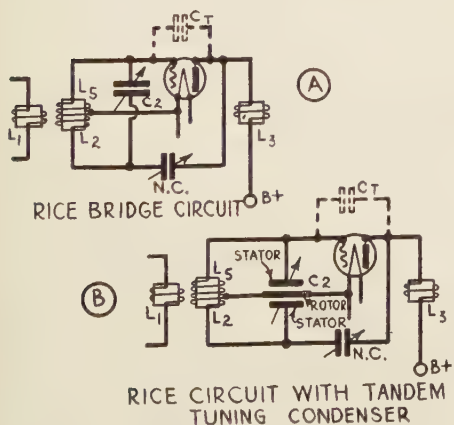


Fig. 83—Rice Bridge Circuit

eliminate hand-capacity effects when tuning. Also, in the circuit of Fig. 83A there is sometimes bothersome coupling between the rotors and frames of the variable condensers unless shielding is employed. Condenser NC must be structurally rigid, since if it should become short circuited, either the "B" supply will be shorted or the "B" voltage will be applied to the filament, burning it out, depending on which terminal of the "A" battery the B— is connected to.

In the Rice circuit, the bridge is balanced for a given magnitude of capacity C_T by so placing the filament tap between L2 and L5 that inductance L5 bears the same ratio to L2 that capacity NC bears to C_T .

Another disadvantage of the Rice circuit is the fact that only the voltage across the L5 part of the tuning coil is applied between the grid and filament of the tube. This is only half of the total signal voltage developed across the tuned circuit if the coil is tapped at its center point.

139. **R. F. L. CIRCUIT:** Fig. 84A shows the R. F. L. bridge circuit developed by the Radio Frequency Laboratories. The feedback neutralizing voltage is obtained by tapping the plate coil L3, not physically but by induction to the coil L5. The condenser C3 in series (considering R. F. current flow) with the plate coil is of large capacity, with consequent low reactance. By making the number of turns in L5 small, the feedback voltage is made a small part of the total R. F. plate voltage and therefore the balance is obtained when NC is large as compared to the grid capacity. This is more convenient in practice. The circuit has been used in successfully several recent commercial receivers.

Fig. 84B shows another popular bridge circuit. An additional coil L3 and small neutralizing condenser NC have been added to the basic amplifying circuit of Fig. 82. The coil L3 is closely coupled to coil L2 so that a voltage operating in L2 will also appear in L3. Capacity NC is made small in size, variable, and approximately the same size as the tube capacity C_T . The coil windings are so related that a voltage built up in coil L3 acts through NC upon the circuit L2C2 in exactly the reversed direction to the normal voltage reacting from L2. This circuit has been used by many manufacturers of tuned R. F. sets, as it is easy to apply and to neutralize. For most complete amplification it would seem that coils L2 and L3 should be arranged symmetrically with respect to the secondary. A suggested coil form for

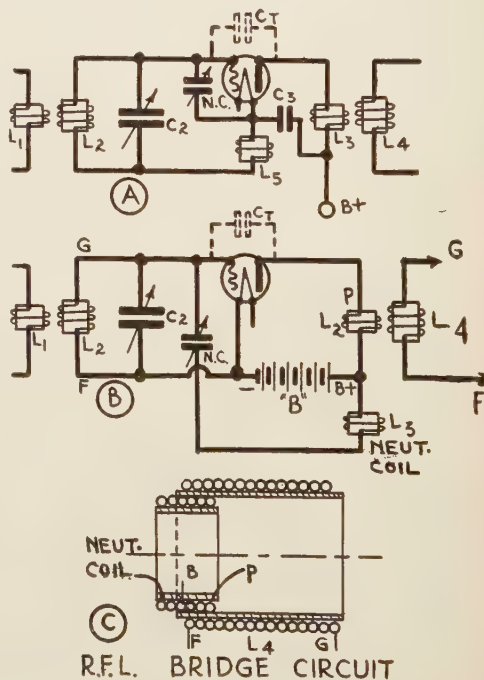


Fig. 84

this circuit is shown in Fig. 84C; L_2 and L_3 have the same number of turns.

140. **HAZELTINE NEUTRODYNE CIRCUIT:** Fig. 85 shows the neutrodyne circuit for the neutralization of the feedback currents. The neutralizing condenser NC is connected from the grid to a tap on the secondary coil L_4 , which is so coupled to the primary coil L_3 in the plate circuit that the voltage across the lower part of the coil L_4 is just opposite in phase and bears a constant ratio to the voltage across L_3 , regardless of the wavelength to which the receiver is tuned. Hence by proper choice of the tap on L_4 and size of NC, the current in NC can be made to introduce on the grid a voltage which just balances that produced by the current through C_T . However, since the coils L_3 and L_4 are wound close together in order to get magnetic coupling between them, there is also some intercoil capacity. This causes the voltage across the secondary coil to depart somewhat from a uniform and constant opposition to the voltage across the primary coil, and the relative phases are made to depend somewhat on the frequency. This is the reason why the degree of neutralization varies to some extent with the tuning on commercial neutrodyne sets. It is also easily possible to get over-neutralization with consequent decrease in sensitivity, unless neutralizing condenser NC is adjusted carefully.

141. **REVERSED TICKLER CIRCUIT:** Fig. 86 shows the Superdyne, or reversed tickler circuit for suppressing feedback. It consists merely of the addition of a tickler coil whose connections are made opposite with respect to those of the tickler in the regenerative circuit. That is, the magnetic coupling between the tickler and the secondary coil L_2 tends to suppress regeneration. It

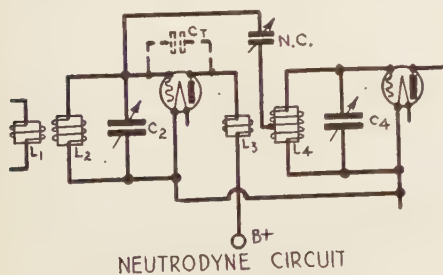


Fig. 85

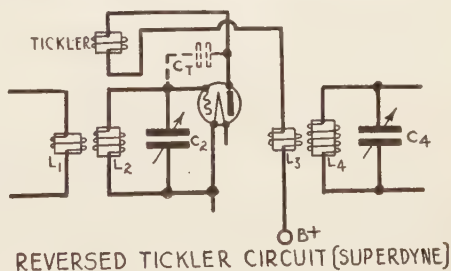


Fig. 86

gives a smooth and efficient control. One inherent disadvantage of this method is that it balances the magnetic coupling of the plate and grid circuits by means of the coils against a capacity coupling of these circuits through the tube capacity C_T . Hence the setting of the tickler must be varied every time the set is tuned to a different wavelength. This means a control in addition to the tuning control for every stage of R. F. used, thus complicating things. The Superdyne circuit has not been popular for a long time.

142. **LOSSER METHODS:** We come now to the various stabilizing methods falling under the class of lossor or absorption schemes. These consist of the deliberate introduction of such losses into the primary or secondary circuits, or both, that the energy fed back through the tube capacity C_T is thereby absorbed and eliminated.

143. **GRID POTENTIOMETER METHOD:** Fig. 87 illustrates one of the older methods used, simply the grid circuit returned to a potentiometer. As the arm of the potentiometer is moved toward the positive end, the grid circuit has a current flowing through it. This current flowing through the resistance of the tuned circuit results in a loss of energy. The tendency of the tube to oscillate is thereby greatly reduced, so is the strength of the signal. Also, as under this condition the grid circuit has a current flowing in it, a load is put on the tuned circuit, resulting in broad tuning. The main advantage of this method is its extreme simplicity and low cost.

144. **PLATE RESISTANCE METHOD:** Fig. 88A shows the plate resistance method of oscillation control. Here a variable resistance R of zero to about 200,000 ohms is put in series with the plate coil. Two opposing actions

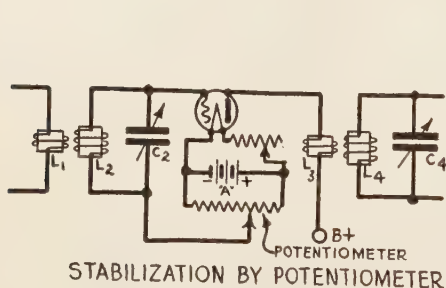


Fig. 87

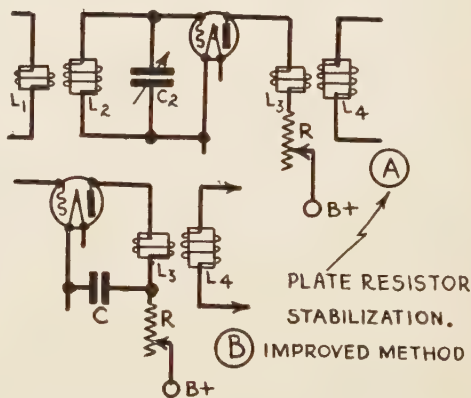


Fig. 88

take place. The value of the voltage impressed on the plate of the tube is lowered, and the plate impedance of the tube is increased (see Fig. 56), thus reducing the plate current and the impedance drop across the primary coil of the tuning transformer. Also with this connection, both the direct current and the R. F. current of the plate circuit flow through the resistor and so additional impedance is placed in the external plate circuit, tending to make the tube more liable to oscillate. However in practice the former tendency overbalances the latter and some advantage is gained. Fig. 88B shows a better connection. Here a by-pass condenser C of about 0.5 mfd by-passes the R. F. currents directly to the filament, keeping them out of the resistor. Resistor R should be non-inductive. This method has the disadvantage that, usually in order to secure effective control, the plate voltage must be lowered so much that the amplification is reduced, and the resistance must be varied as the wavelength is varied.

145. **FILAMENT CONTROL:** Oscillation control by reduction of the filament voltage of the tube can be used in a limited way, but in most cases when it is reduced enough to really be effective, the amplification is also reduced.

146. **LOSSER RESISTANCES:** Fig. 89 shows a one stage amplifier in

which various resistances have been incorporated to act as lossers. Actually in a practical circuit usually only one of these would be employed, but they have all been incorporated in the diagram for easy reference. Losser circuits of this type are widely used because they are very simple and cheap.

R1A, a resistance of about 500,000 ohms, can be placed across the grid coil. It broadens the tuning somewhat but in a two or three stage amplifier, if it is placed across the second R. F. coil, it will control the oscillation tendencies of all tubes. The resistance should be non-inductive and also non-capacitive, or it will change the tuning of the stage when it is varied, since it is directly across the tuned circuit. It must be varied as the wavelength is changed. This scheme is useful in A. C. tube electric sets.

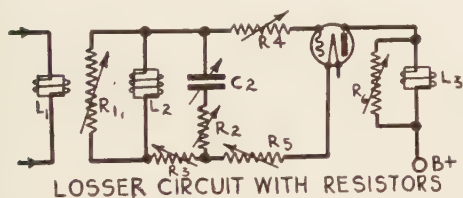


Fig. 89

R3 must be non-inductive and non-capacitive as it is included in the tuning circuit. This method is also impractical.

R4 and R5 are resistors placed in the grid circuit and grid return circuit respectively. This method is practical and is used extensively in commercial receivers. R4 has the disadvantage that, being at grid potential, it cannot be touched for adjustment without disturbing the playing of the set, unless it is built with an adjusting screw which can be varied with an insulated screwdriver.

R5 raises the condenser shaft above filament potential, necessitating an insulated condenser shaft if hand capacity effects are to be eliminated. In shielded sets, the condenser shaft must also be insulated from the grounded shield. If gang condensers are used, it means insulated couplings between all condenser rotors, which is impractical.

When R4 is used, it is made either fixed or semi-adjustable, and of a resistance between 400 and 1,000 ohms. The resistance valve is not critical. The resistors should be non-capacitive and non-inductive. The theory of this *grid-suppressor* system is that when a tube oscillates there is a certain amount of current flowing in the grid and the insertion of the grid-suppressor resistance acts to prevent this current flow. During the normal operation of the tube there is merely a voltage variation in the grid and little or no current. Therefore, when the tube starts to oscillate the resistance absorbs the current and the tube stops oscillating, the action being entirely automatic. This method is being used extensively, since it is cheap and simple. Grid suppressors are available in various resistance sizes. In a multiple stage amplifier it is common to put a grid suppressor in each R. F. stage excepting the antenna stage.

R6 is a variable resistance shunted across the primary of the R. F. trans-

R2 is a resistance in series with the tuning condenser. This broadens the tuning, and introduces hand capacity effect because it raises the potential of the condenser rotor above that of the filament. It is impractical.

R3, a resistance of about 50 ohms, is in series with the grid tuning coil. This broadens tuning and must be adjusted as the wavelength changes.

former. This by-passes some of the R. F. currents from the primary and prevents oscillation by reducing the amplification to a point below the oscillation point. It must be varied as the wavelength is varied. It has some advantages when used in A. C. sets.

147. TUNED ABSORPTION SYSTEM: A novel method of stabilizing R. F. amplifiers consists in the coupling of a tuned absorption circuit to the secondary of the R. F. transformer, as shown in Fig. 90. The absorption circuit consists of a coil L_5 and a fixed or variable condenser C_5 . If a fixed condenser is used, the absorption coil is usually wound with about half as many turns as secondary coil L_2 , and the condenser C_5 is half the capacity of the variable tuning condenser C_2 . The absorption coil can be wound on a form slightly smaller than the secondary and slipped inside the secondary coil. It should then be moved or adjusted so that maximum sensitivity is obtained without oscillation. The absorption will be maximum at the high frequencies, thus compensating for the increased tendency toward oscillation at these lower wavelengths. Of course, the great objection to this method is the decrease in sensitivity of the set produced by the loss of energy in the absorption circuit, and the fact that the amount of absorption is bound to be excessive at some wavelength. If the absorption circuit is tuned by a variable condenser, some of these objections are eliminated, but one more control is added to the set.

148. EDDY CURRENT ABSORPTION SYSTEM: Another method of oscillation prevention which has been used by manufacturers of low-priced receivers, because of its simplicity and absence of cost, is that of mounting the tuning coils with their ends close to the metal ends of the variable tuning condensers, or other pieces of metal as shown in Fig. 91.

The magnetic field of the coil linking with this metal sets up eddy currents in the metal which dissipate in the form of heat. Thus the increased magnetic field created by self oscillation is quickly dissipated in the metal end plate and the oscillation is suppressed. The advantage of this method is of course in its extreme

simplicity and absence of any extra variable control, but since a loss due to eddy currents is constantly taking place during the normal operation of the receiver, decreased sensitivity results and selectivity is decreased. One manufacturer has used a metal vane in the field of the coil. This was so arranged by connection with the condenser shaft that as the condenser was rotated during tuning. The metal vane was moved toward or away from the coil, thus securing the proper amount of lossing at every frequency to keep the set just below oscillation.

149. PHASATROL METHOD: Fig. 92A shows the Phasatrol method devised by John Rider. This is neither an absorption nor a bridge circuit, but

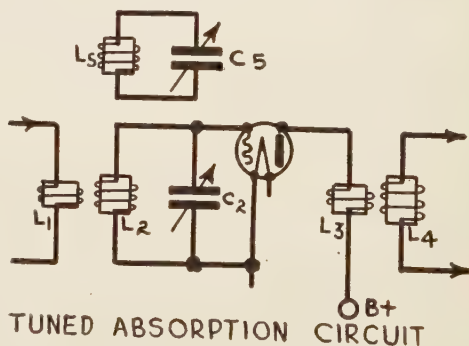


Fig. 90

may properly be called a phase shifting circuit. In this circuit a fixed condenser C3 of proper capacity is placed in series with the primary of the R. F. transformer and a variable high resistance is shunted across both. The first function of the resistance is to supply a path for the direct plate current of the tube since the condenser does not allow direct current to flow through it. The action involved is rather technical but will be given here for those interested.

In an ordinary tuned R. F. circuit, such as Fig. 82, the external plate circuit, consisting of coil L3, is practically purely inductive. Therefore when the plate current of the tube undergoes a variation due to the action of the signal potential on the grid of the tube, the voltage variations across L3 lag the plate current changes (and the signal potential changes on the grid) by about 90 degrees. Therefore the plate potential variations caused by this signal also lag the plate current variations by about 90 degrees. When these potential variations (of this phase relation) act through the tube capacity CT, to send currents through the grid circuit, the condenser CT shifts the phase causing the current to lead the plate potential variations by 90 degrees. The net result is that the feedback cur-

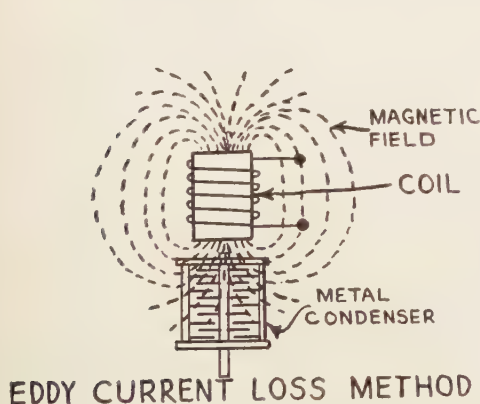


Fig. 91

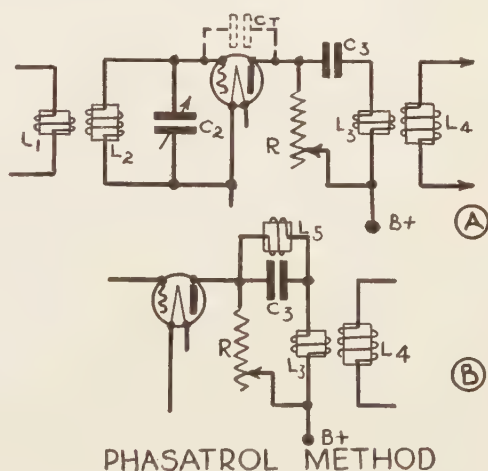


Fig. 92

rent is in phase with the signal impulses in the grid circuit and produces regeneration and oscillation. Now it is evident that if the phase relation of these plate potential variations could be shifted 90 degrees out of phase with the signal impulses, no oscillations could take place because with such a phase difference there is no *continuous* reinforcement of the original impulse. We do not want this phase difference to be 180 degrees, because then the feedback current would at all times directly oppose the signal current and thereby materially weaken the signal.

The 90 degree shift of phase is accomplished by inserting the condenser C3 in series with L3. Since the plate circuit now consists of a capacitance and an inductance in series, the plate potential variations are approximately in phase with the plate current variations, and hence the feedback currents are approximately

90 degrees out of phase with the signal impulses. Since the resistance R is non-inductive and non-capacitive, any R. F. currents flowing through it do not produce any phase displacement. It must be used, since if the $B+$ terminal were run directly to the plate, the condenser $C3$ and coil $L3$ would be short-circuited.

The commercial form of Phasatrol consists of a fixed condenser of .002 mfd. and a variable high resistance of 0-10,000 ohms (adjustable by a screw driver inserted in its slotted shaft) enclosed in a Bakelite housing. Due to the stray magnetic and capacitive coupling in almost every receiver, the value of the resistance has to be regulated carefully for best amplification, because the circuit, consisting of non-inductive resistance, capacitance and inductance, can be made to function as an almost ideal absorption circuit which is tuned directly to the desired wave lengths by the presence of the tuned secondary circuit. This resistance damps the circuit, so that by adjusting it to the desired value it is possible to cure even the most obstinate oscillating circuit. Its value can be adjusted to a permanent value for an amplifying tube; or for fine control of sensitivity over the waveband, it can be mounted on the front panel and varied when necessary. It is obvious that variation of the resistance also results in variation of the plate impedance of the tube, with the results explained in a previous paragraph.

The sensitivity of a receiver using the Phasatrol system can be increased on the higher wavelengths of the broadcast band by connecting a small R. F. coil $L5$ across the phase shifting condenser, as shown in Fig. 92B. This coil serves to increase the feedback at the wavelengths to which it is tuned and naturally increases the R. F. amplification at these waves. A coil of about 40 turns of No. 30 D. S. C. wire wound on a $\frac{3}{4}$ or 1 inch diameter tube works well with .002 mfd. condenser $C3$. This tunes the coil to a wavelength near the upper end of the band, where the loss of efficiency usually occurs. As the coil is tuned more or less sharply the operation at the lower wavelengths is not affected.

150. CHOICE OF OSCILLATION PREVENTER: After this discussion of all the common methods of oscillation prevention, the novice will probably wonder which one is best. This is a difficult question to answer off hand, as it depends on many factors. It is fairly true that in a large number of stages the bridge systems are best, because non-regenerative perfectly balanced bridge stages giving as high as 20 gain per stage (with ordinary 3 electrode tubes) can be cascaded to almost any practical number of units. This is not true of regenerative loss-stabilized receivers, as the tendency toward oscillation increases much faster, as the number of stages increase, than does the overall amplification. That is, each stage gives a smaller amount of amplification than the preceding one. Thus two stages will not give the square of a single stage gain, or three stages give the cube, as do the best of the carefully designed bridge circuit, but will give a great deal less. Increasing to four or five stages may actually give a decrease in gain, although selectivity is improved. When only one or two stages of R. F. amplification are used, some of the loss-stabilized, and the phase shifting methods give very good results.

From the manufacturer's point of view, the method of stabilization used is usually influenced by patent situations. The neutrodyne as well as most of the other bridge circuits are patented, so that manufacturers using these methods are licensed and pay royalties. Most of the simple lossier methods are not patented

and are free for use by anyone. The home set builder is free to use any of the methods. Sometimes the placement of the coils and wires in a set is such that neutralization is automatically obtained without further trouble, but usually if the tubes do not oscillate when no stabilizing devices are used, it is a sign of an inefficient set. The maximum sensitivity is obtained when the tubes are working just below the point of oscillation, which means that a limited amount of regeneration must be present.

The development of the four electrode screen-grid tube with its exceedingly low inter-electrode capacity has more or less taken care of the problem of feedback and oscillation in modern receivers. Feedback through the capacities of the elements of these tubes is so small that no special precaution is necessary to prevent it. This will be discussed more fully in a later chapter.

REVIEW QUESTIONS.

1. Explain the action of a single stage of R.F. amplification.
2. What harmful effect does feedback cause in an R.F. amplifier?
3. What is the function of stabilizing devices in R.F. amplifiers?
4. State three general methods of amplifier stabilization.
5. Explain the principle of the neutrodyne circuit.
6. Explain the plate resistance method of stabilization.
7. Explain the "losser" methods of stabilization.
8. Describe several practical methods of stabilization by the eddy current loss method.
9. What is the effect of introducing too much loss in an R.F. amplifier in an attempt to stabilize it?

CHAPTER 12.

PRACTICAL CONSIDERATIONS IN R. F. AMPLIFIER DESIGN.

DESIGN OF TUNED R. F. TRANSFORMERS — RESONANCE FORMULAS — RESONANCE ACTION — TUNING — RESISTANCE $\%S$. SELECTIVITY — CUTTING SIDEBANDS — MULTIPLE STAGE SELECTIVITY — COIL LOSSES — COIL SHAPES AND FORMS — DESIGN OF TUNING COILS — PRIMARY COIL DESIGN CONSIDERATIONS — COUPLING — INTERSTAGE COIL COUPLING AND ITS ELIMINATION — SHIELDING — R. F. CHOKES AND BY-PASSES — BY-PASS CONDENSER REACTANCES — COUPLING IN "B" SUPPLY — CONSTANT R. F. COUPLING

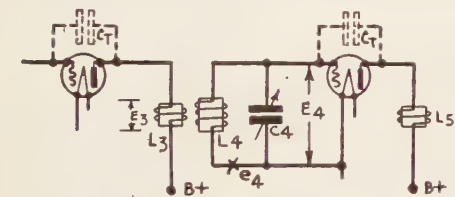
151. **TUNED R. F. TRANSFORMER:** The popularity of the tuned R. F. receiver is so great that a discussion of the design factors of the coils and condensers used in it will be considered here. The sizes, shapes and electrical constants of these parts vary greatly in the different commercial sets, so that only a few of the outstanding ones will be described.

Thus far the coupling coils or transformers used in tuned R. F. transformers have been referred to in an abstract way, no attempt being made to study their design in detail. This will be done now. A study of articles on the construction of broadcast tuners reveals the disturbing fact that very few agree on any one standard value for diameter of coil, size of wire, method of winding, number of primary and secondary turns, etc. This condition is explainable when we consider that factors of space, cost, number of tubes, circuit used, etc., govern to a large extent the design of the individual parts. The same condition exists in the automobile industry where we have many different designs of automobiles, although they are all intended for the same purpose. Each make is a reflection of the collective ideas of the designers.

152. **INTERSTAGE COUPLING COIL DESIGN:** The tendency in modern receivers is toward the use of the air-core type of R. F. transformers in which the primary and secondary windings are on thin tubes of insulating material such as Bakelite or Formica. The windings consist of either cotton, silk or enamel covered copper magnet wire, the latter being used extensively on account of its lack of moisture absorption and better mechanical characteristics for quantity production machine winding. The secondary winding is usually tuned by a variable condenser, to produce resonance.

Now let us study the various factors governing the construction of an interstage tuned R. F. transformer, considering the secondary coil first.

153. WHAT HAPPENS IN THE TUNED CIRCUIT: In Fig. 93 let us consider L3, L4 to be a tuned interstage coupling transformer connected between two tubes of an R. F. amplifier. Let us assume that no tuning or separation of stations has been accomplished ahead of this stage. Then coil L3 has currents of various frequencies flowing in it, due to the signals of all the stations received by the antenna. These set up corresponding varying magnetic fields around L3. If L3 is placed near coil L4 so that at least part of its magnetic field links and unlinks with it, induced voltages of these various frequencies are set up. Since they are set up in the windings of L4 they can be considered as voltages acting in series with L4. Now the function of the tuned R. F. transformer is threefold.



VOLTAGES IN A TUNED RF. CIRCUIT

Fig. 93

First, as much energy as possible must be transferred from L3 to L4 by means of the magnetic field acting as a coupling agent. (This will be considered later). Second, the voltage in L4 set up by the station to be received must be separated or made to predominate over the voltages of all the other stations. Thus, this voltage acting between the grid and filament of the vacuum tube must be made as large

as possible, in order to produce a maximum change of plate current to be transferred on to the next stage. The last two actions are brought about by tuning the circuit to a condition of resonance by means of a condenser C4 connected as shown. This forms a series tuned circuit, since the source of e.m.f. e_4 , is in series with the coil and condenser.

154. RESONANCE: One of the most important characteristics of a series tuned circuit is that for a given combination of inductance L4 and capacity C4, the reactance (opposition to current flow) of the inductance ($2\pi fL$) to current of a certain frequency is equal and opposite to the reactance of the condenser

$\frac{1}{2\pi fC}$ for currents of this same frequency. Therefore, since these two balance each other out, the total impedance or opposition to the flow of current of this frequency is merely equal to the natural resistance R of the tuned circuit (see article 30 in chapter 2). This is called the resonant frequency of the tuned circuit. Since under this condition

$$2\pi fL = \frac{1}{2\pi fC} \text{ we find by solving this equation that}$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Where f = frequency in cycles per second at resonance,
 L = inductance in henries at resonance
 C = capacity in farads at resonance.

This can be expressed in terms of the wavelength if we remember that

$$\text{Wavelength} = \frac{300,000,000}{f}$$
$$\text{or } f = \frac{300,000,000}{\text{Wavelength.}}$$

Substituting this value of f in the equation above we obtain

$$\frac{300,000,000}{\text{Wavelength}} = \frac{1}{2 \pi \sqrt{L C}}$$
$$\text{or Wavelength} = \frac{300,000,000}{2 \pi \sqrt{L C}}$$

If L is expressed in microhenries and C is expressed in microfarads, as is usually the case, this equation becomes

$$W. L. = 1885 \sqrt{L C} \dots\dots\dots (11)$$

where $W. L. =$ Wavelength in meters.

This formula makes it possible to compute the combination of inductance L and capacity C necessary to tune a series circuit to resonance at a particular wavelength.

Now getting back to our discussion of resonance, it is evident that these induced voltages of various frequencies existing in coil L_4 will attempt to send currents around the closed tuned circuit $L_4 C_4$. However, the current set up by any alternating voltage is equal to the voltage divided by the total impedance of the circuit. Therefore, if the circuit is tuned, say, to 600 kilocycles (500 meters) an induced voltage in L_4 having a frequency of 600 kilocycles is able to send a comparatively large current through the tuned circuit. The strength of this current is determined by Ohm's law and is therefore equal to the impressed voltage in coil

L_4 divided by the *total resistance* of the tuned circuit or $\frac{e_4}{R_4}$. This resistance consists of the sum of the resistances of the coil, connecting wires, and condensers.

These resistances are the A. C. resistances measured at the frequencies considered. The resistance of a coil is much greater on high frequency A. C. than it is on direct current. A voltage having 610 or 590 kilocycles frequency sets up a smaller current in this circuit, because it must not only overcome the natural resistance of the circuit, but the impedance offered by the coil and condenser to currents of this frequency as well. As we go further from this resonant frequency down to 580, and up to 620 kc., etc., the impedance becomes

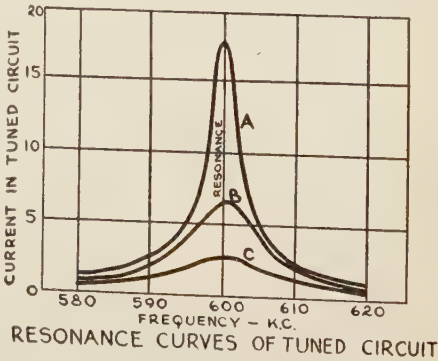


Fig. 94

greater and greater and the current is diminished. This is shown graphically by the tuning curve A of Fig. 94. Notice the large current set up by the voltage of resonant frequency. This current, circulating through the inductance L_4 , builds up a larger voltage E_4 across L_4 C_4 circuit. This is the A. C. grid potential applied to the tube, and is amplified by the tube. Notice that E_4 is much larger than e_4 depending on the size of the inductance L_4 and its resistance. It would seem to be advisable to make L_4 large in order to make E_4 as large as possible. However, the resistance of a solenoid tuning coil increases almost in the same proportion as the inductance is increased by adding more turns on the end of the coil. Therefore the current in the tuned circuit would be materially reduced by this extra resistance, so that the net gain would be problematical. The use of an inductance coil large enough to cover the broadcast tuning range with a .00035 or .0005 mfd., variable tuning condenser has been accepted as a good compromise.

A thorough understanding of this theory of the tuned circuit is essential at this point. The essential points to be remembered are that the signals of many stations are received simultaneously by the set. Tuning does not cut one station in and the other out entirely. It merely makes *one signal maximum in strength and weakens all other signals*. These other signals are still there, and their currents are of varying strength. They are transferred from stage to stage, and if their strength is great enough they cause interference. All that tuning does is to balance the tuned circuit at the point where for that particular frequency the opposition to other frequencies a maximum. In order to do that at the same time, there would have to be set up a *rejector* circuit for each of the other frequencies. This is sometimes done by a wave trap of the rejector type.

155. VARIABLE TUNING: Since, in the practical receiver, we want to be able to tune the set to a number of stations of different frequencies successively, the tuned circuits must be made adjustable so as to produce resonance at these frequencies. This can be done either by varying the inductance alone, varying the capacity alone, or varying both. The first method is employed in a few receivers, one example being the Kellogg set. The third method is not being used commercially at present, to the writer's knowledge, since it makes the set complicated. The second method is the one used in the majority of receivers. When the tuning dial or dials are adjusted on the set, to tune in a station, the condensers in the tuned circuits are being rotated to change the capacity.

156. RESISTANCE AND SELECTIVITY: What we desire in the secondary coil L_4 is inductance and nothing else. Actually it is impossible to obtain this alone, since the coil being made of wire, has resistance also. This A. C. resistance should be kept as low as possible by proper design, since the current flow at resonance is limited only by this resistance. The currents flowing at frequencies other than the resonant frequencies are also reduced by resistance as shown by curves B and C of Fig. 94. "B" is the resonance curve when a medium amount of resistance has been included in the tuned circuit, C is for a greater amount of resistance. Notice that these curves are flattened somewhat, showing that for a tuned circuit containing appreciable resistance the increase of current at resonance is not as great proportionately as is the case in a circuit of low resistance. This means that the selectivity is greatly decreased since the signal current of the

wanted station is only slightly stronger than that of the unwanted stations, so they all come in with nearly the same volume.

The curves of Fig. 94 can be plotted in another way, in order to bring out another important point regarding selectivity. In Fig. 95, the curves have been re-plotted to show the relation between frequency in kilocycles and per cent of the response at resonance. Curve A is for the circuit of very low resistance, B is for a circuit having higher resistance, and C is for one having still higher resistance. At resonance the response for all curves is 100 per cent. The response at any other frequency is plotted in terms of the percentage of the response at resonance. Notice that the curves having resistance and broad tuning are wider, showing that the response for a signal slightly off the resonant frequency is not much less than that of the resonant signal.

157. **SIDE BANDS:** The A. C. resistance of a good isolated tuned circuit is around 12 ohms at a frequency of 1,500 kilocycles (200 meters). However, its

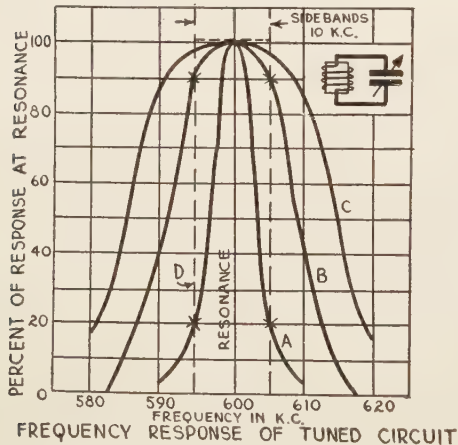


Fig. 95

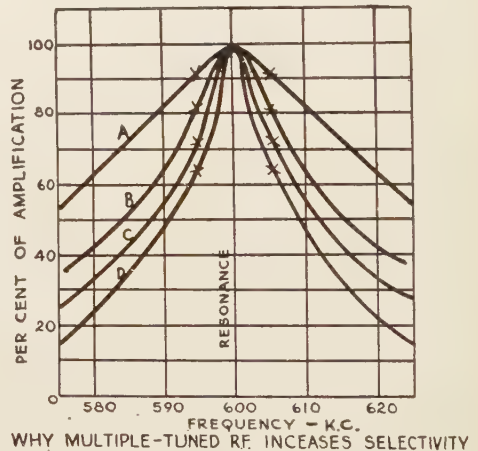


Fig. 96

behavior when placed in a receiver depends largely on what circuits are brought into electrical association with it, and what mechanical things are brought near its field. The associated circuits consist of coupled primaries and the input circuits of vacuum tubes which are connected directly across the tuned circuits. The mechanical things include condenser metal and plates, shielding, etc. From the standpoint of signal strength and selectivity alone, all these factors should be controlled so that a low resistance results in the tuned circuits. However, the resistance can be made so low, and the tuned circuits made to tune so sharp that an undesirable effect is produced. This is known as *cutting sidebands*. Curve A of Fig. 95 has purposely been drawn to illustrate this condition.

Consider that a musical selection is being received from a station transmitting at 600 kilocycles (500 meters), through the tuned circuit A. It will be remembered from a discussion in an earlier chapter that the complete range of musical frequencies broadcast lies between about 30 and 5,000 cycles. Therefore at the

broadcasting station the 600,000-cycle carrier current wave is modulated by the audio frequency currents ranging from 30 to 5,000 cycles. Consider first that only a 5,000-cycle note is being played by the orchestra. This 5,000-cycle audio current then combines with the 600,000-cycle carrier current producing two currents, one having a frequency equal to the sum of these two (605,000 cycles) and one having a frequency equal to the difference of the two (595,000 cycles). Therefore to receive this note, the R. F. amplifier must pass these two currents through it with equal strength. You will notice that they differ in frequency by 10,000 cycles, or 10 kilocycles. Now if a 3,000-cycle note is played, the carrier wave will contain a 603,000-cycle note and a 597,000-cycle note and the amplifier will have to amplify these equally. It can be seen that if the entire range of musical frequencies is being covered at once by the orchestra there will be present a carrier wave covering a band of frequencies from 605,000 cycles to 595,000 cycles, and in order to secure faithful reproduction at the receiver, *every one* of these frequencies must be *passed through the R. F. amplifier and amplified equally*. If any frequency is lost or suppressed in the amplifier, then that note will not be reproduced in the loudspeaker, and the music will not be a true reproduction of that played in the broadcast studio. This condition would occur if the frequency response of any one tuned circuit or of the entire R. F. amplifier were as shown by curve A, Fig. 95. The 5 kilocycles above the carrier and the 5 kilocycles below the carrier (10 kc. altogether) constitutes what are known as the "*sidebands*."

It is evident that the response for the 595 and 605 kc. sidebands (5,000-cycle audio note) is only 20 per cent as large as the response of sidebands near resonance (low note). Therefore this high 5,000-cycle note would hardly be heard in the loudspeaker. Other notes lower than this would be suppressed in varying degrees as shown. This frequency response is evidently too sharp.

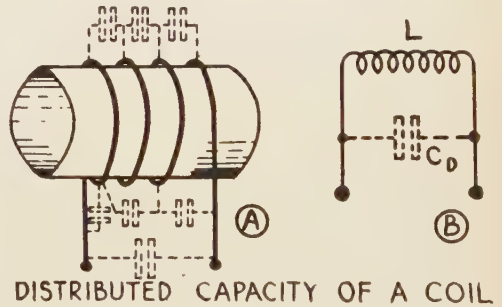
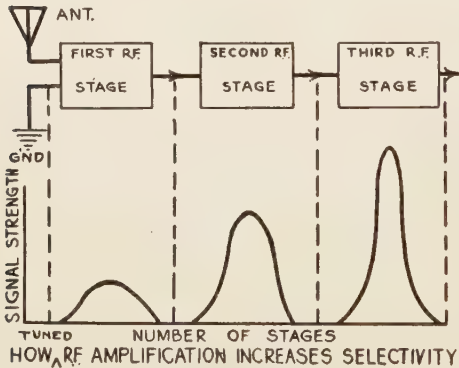
Tuning characteristics represented by curve B would be more nearly ideal, since the response at 545 kc. is 90 per cent of the response at resonance. Curve C is obviously a further improvement in this respect. However, curves B and C indicate broad tuning with poor selectivity and consequent danger of station interference. It can be seen that with this type of tuned circuit some compromise must be effected. Some compensation for the loss of the high frequency notes due to cutting of side bands by over-selective tuning circuits can be secured in the audio amplifier and reproduced by designing these to have a rising characteristic at the high frequencies. This means selecting the audio and reproducer units to match the operating characteristics of the R. F. amplifying system.

Obviously the ideal response curve would be that shown at D, Fig. 95. The curve has straight vertical sides and a flat top and is 10 kc. wide. Since the peak of the wave is no greater at the carrier than at 5 kc. above or below the carrier, equal transmission is obtained on all frequencies within the 10 kc. side band range. A frequency curve approaching this can be secured by a tuning system known as the Vreeland band selection system.

158. **SELECTIVITY OF MULTIPLE STAGES:** The selectivity of an R. F. amplifier depends on the number of stages, tightness of coupling in the R. F. transformers, amount of regeneration, etc. Fig. 96 explains the first factor. Let curve A represent the response curve of a single R. F. stage. For a frequency 5 kc. off resonance, the circuit gives about 90 per cent of the amplification at

resonance; at 10 kc. off resonance the amplification has dropped to 81 per cent. Now if another stage with characteristics exactly identical to the first is added to it the selective action shown by curve B is obtained. This can be understood from the fact that if at a certain frequency off resonance the first stage reduced the amplification to 90 per cent, then the second stage would reduce the amplification to 90 per cent of what came through the first stage, i. e., 90 per cent $\times$ 90 per cent or 81 per cent. A third stage would reduce it to 81 per cent $\times$ 90 per cent or 73 per cent. A fourth stage would make it 73 per cent $\times$ 90 per cent or 66 per cent, etc. Reference to the curves at a point 5 kc. off resonance shows the selective action referred to above. Under these conditions of selectivity, since a sideband of 5 kc. resonance is reduced to 66 per cent strength, considerable sideband suppression would result, with consequent signal distortion.

Fig. 97 shows in a pictorial way how the signal strength is increased and the width of the frequency band passed through is decreased as the number of tuned R. F. stages are increased. It is obvious that the tuning of each stage must be



Left: Fig. 97. Right: Fig. 98

designed to be broader than that desired from the amplifier as a whole. By proper design of the individual tuning circuits it is possible to secure an overall response curve approaching the flat topped curve of Fig. 95.

159. **COIL LOSSES:** Although extreme selectivity is undesirable from the point of view of sideband suppression, it is usually advantageous to keep the resistance of the tuned circuits as low as possible in order to secure maximum amplification, and secure the right amount of selectivity by proper coupling of the primary and secondary coils. The sum total of all the losses in a tuning coil are usually lumped and expressed as the A. C. *resistance* of the coil. While this is not technically correct, it has become the accepted practice, since the final effect of these losses is to reduce the current in the tuned circuit, just exactly as if the tuned circuit had no resistance and we inserted resistance in it by means of a rheostat.

One source of loss, known as the *skin effect*, is due to the fact that at the high frequencies the currents travel only over the surface or "skin" of the wire, thus making only a small proportion of the total cross-sectional area of the wire effective in carrying the current, increasing the resistance.

Another is that due to the eddy currents set up in the wires of the coil by the varying magnetic field. This increases as the diameter of the wire used is increased. The total resistance of R. F. coils increases greatly as the frequency is increased. The amount of resistance increase depends on the shape of coil and size of wire. For instance, a single layer solenoid coil of 300 microhenries inductance, consisting of about 58 turns of No. 28 D. C. C. (double cotton covered) wire wound on a 3-inch diameter tube, was measured and found to have a resistance of 3.15 ohms on direct current, 6 ohms at 500 kilocycles (600 meters), 10 ohms at 1,000 kilocycles (300 meters) and 14 ohms at 1,500 kilocycles (200 meters).

160. DISTRIBUTED CAPACITY: Another undesirable coil characteristic is known as the distributed capacity. Since the various turns of a coil are conducting surfaces separated by insulating materials, they form tiny condensers. The adjacent turns are at different voltages, so that at high frequencies, small alternating currents exist in these distributed condensers (Fig. 98A). By imagining all the little distributed capacities of these condensers lumped into one condenser, the coil may be considered as a pure inductance with a condenser C_D in parallel. At low frequencies the condenser effect is negligible and all the current flows through the wire. However, if the frequency is progressively increased, the reactance of the inductive part of the coil increases and that of the distributed capacity decreases, until a point is reached where practically all of the current passes through the distributed capacity, and the coil behaves like a condenser. The working frequency range of a tuning coil must be necessarily small if it is to have constant inductance. Since there are losses in these small condensers due to the solid insulating material, the apparent resistance of the coil is increased by their presence.

It is for this reason that tuning coils should not be coated with shellac and other "dope" preparations which increase the distributed capacity effect and also the losses. Distributed capacity in a tuning coil is also a disadvantage, since it lowers the frequency range over which a coil can be tuned by an external condenser; for even when the external condenser is at its minimum value, the full distributed capacity is shunting the coil. If high inductance values, necessitating the use of multilayer coils, are necessary, the windings should be bank-wound (Fig. 99F) to reduce the distributed capacity.

Just as the capacity of a condenser may be decreased by decreasing the size of the plates or increasing the distance between them, the distributed capacity of a coil can be reduced by using a smaller wire or by leaving a space between the adjacent turns of a coil. The size of the wire cannot be decreased too much, for the resistance will then increase, and the distance between turns cannot be made too large, for the inductance will then be decreased, necessitating more turns for a given value with consequent increased resistance and added capacity. On a solenoid, cotton covered wire around No. 24 B. & S. gauge wound tight, already has enough spacing between the conductors due to the double thickness of the insulation. When enameled wire is used a spacing equal to half the diameter of the wire may be employed. The wire is usually wound in a spiral groove, machine-cut lightly into the coil form. This gives accurate spacing. It is obvious that the distributed capacity increases with the diameter of the coil, since this increases the effective surface area.

161. **TYPES OF COILS:** Lorenz developed a coil having a low distributed capacity. By winding the wire on a series of pegs arranged in a circle he was able to zigzag it as shown in Fig. 99A. No two wires are parallel to each other for any distance at close proximity.

Another way of reducing capacity is by winding the coils on flat strips mounted radially like the spokes of a wheel as in Fig. 99B, and zigzagging the wire. This is known as the spiderweb coil.

The honeycomb coil, Fig. 99C, is used where large values of inductance are required. It is mounted on a base having two contact pins for plugging in a receptacle. The turns of each adjacent layer are made to cross each other at different angles. They may be purchased in a wide variety of sizes.

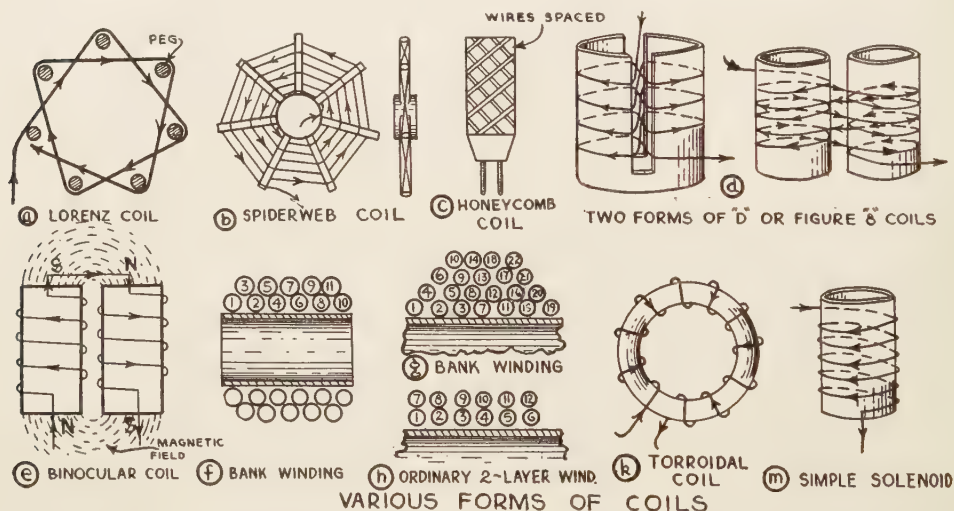


Fig. 99

Fig. 99D shows a D or "figure 8" coil, so called because each of its two halves form the letter D, and the whole coil forms a figure 8. It is wound by slotting a tube or may consist of two separate interconnected coils. The magnetic fields of the two coils aid each other inside the tube and oppose each other outside so that a very small external magnetic field is produced. This reduces stray magnetic coupling with other coils in the receiver.

Fig. 99E shows a binocular coil. This consists of two separate coils connected in series, and having magnetic fields as shown. This also has a very restricted external magnetic field, is easier to construct and is more efficient than the D coil.

Fig. 99F shows a two-layer bank wound coil and Fig. 99G shows one of four layers. This type of winding is used where a large inductance is required with a small distributed capacity. The turns are staggered and wound in the order shown so that adjacent turns have only a small potential difference existing between them, thus reducing the currents flowing through the distributed capacity. Compare these with the ordinary two-layer winding of Fig. 99H. Fig. 99K shows a torroidal coil. This has practically no external field.

While these and many other forms of coils have been developed for special purposes, the fact remains that for a given amount of inductance (within the broadcast frequency range) the most efficient coil is one of simple solenoid form (Fig. 99M) having a ratio of diameter to length of about 2.5. This ratio can be reduced to about 1 without seriously affecting the efficiency of the coil. On broadcast wavelengths it makes little difference whether the coil is self-supporting or whether it is wound on a thin insulating form. The latter is preferable for its mechanical rigidity. It is not necessary to use wire larger than about 24 B. & S. gauge. No. 26 or 28 can be used satisfactorily. (See Technologic Paper No. 298 of Bureau of Standards.) The design of a tuning coil of this type will be considered.

Now it is evident that for practical reasons coils must be made of a definite size and of proper rigidity. Since the position of nearby metallic objects causes losses due to absorption of energy due to the setting up of eddy currents, and interstage coupling is undesirable, the sizes and shapes of coils vary. Some coils are 3 inches in diameter, some 2 inches and lately coils as small as 1 inch in diameter have come into extended use on account of their limited external field.

162. DESIGN OF SECONDARY COIL: The design of the secondary coil for the usual type of simple solenoid transformer with untuned primary and tuned secondary will now be undertaken.

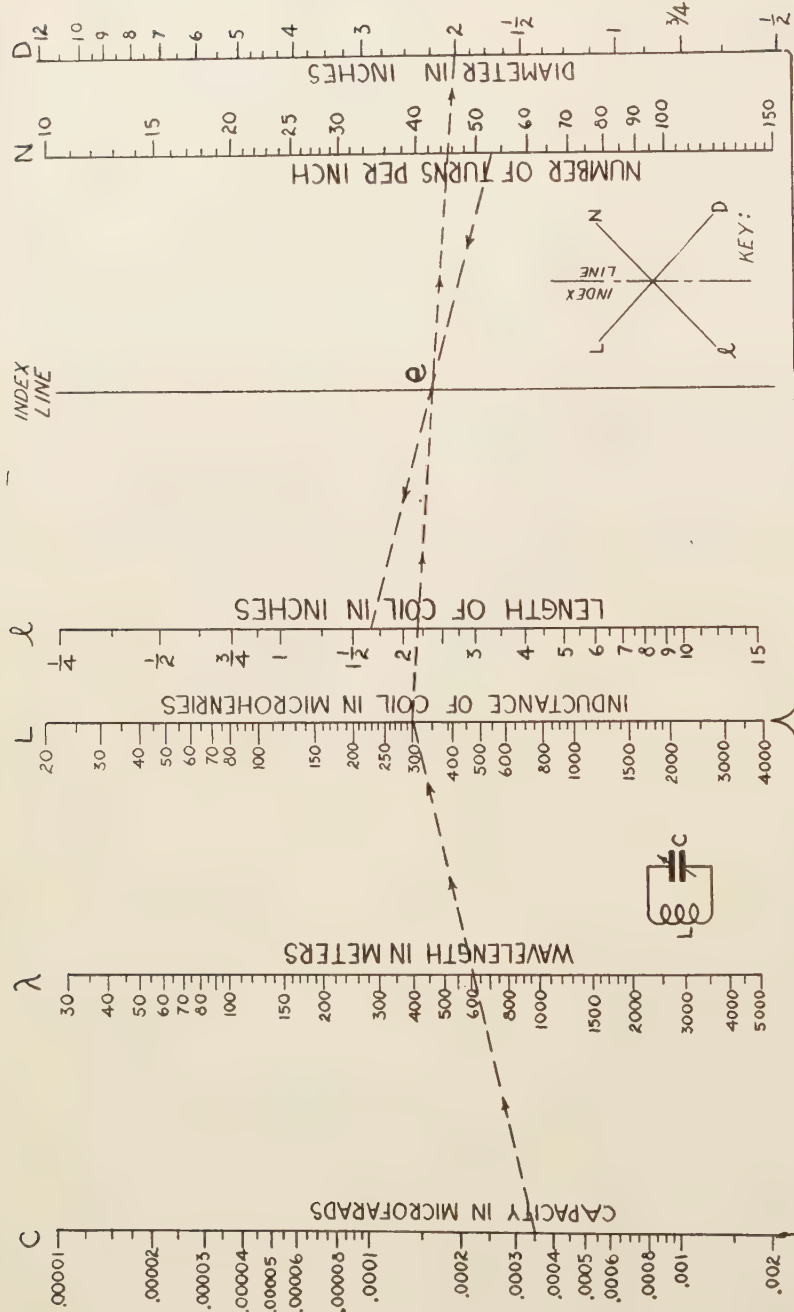
First, since the tuning unit is to be used over the broadcast range, we know that it must have a tuning range from 600 meters down to 200 meters or lower. Many combinations of inductance and maximum capacity values can be used, but present-day practice recommends either a 0.0005 mfd. variable condenser (maximum capacity with plates all meshed) or a 0.00035 mfd. condenser for tuning. The condenser will have a certain minimum capacity (plates all unmeshed), which, together with the inductance and distributed capacity of the coil, will determine the minimum wave length to which the circuit can be tuned. It is best to calculate the dimensions of the coil necessary to tune to the higher wave length with the maximum capacity of the condenser first, and then check back the minimum wavelength on this basis to see if it falls within the required range. There are many formulas which can be used in the calculation of the various factors, but as the average experimenter is usually baffled by these, several charts have been included in this book for determining these constants with the aid of a ruler and a pencil, with a fair degree of accuracy.

Let us assume then that we have a variable condenser whose maximum and minimum capacities are 0.00035 and 0.00003 mfd., respectively. The broadcast range from 200 to 600 meters is to be covered with a tuning coil 2 inches in diameter, wound with number 28 D. S. C. (double silk covered wire).

First the inductance necessary to produce resonances at 600 meters with a capacity of 0.00035 mfd. can be calculated from the formula $W. L. = 1885 \sqrt{LC}$ where L is in microhenries and C is in microfarads. It can be changed to the form

$$L = \frac{\text{Wavelength}^2}{1885^2 C}$$

A simple way is to find it from chart 1 of Fig. 100. This chart is used by connecting the points representing any two known values by a straight line and



SOLENOID COIL DESIGN CHARTS

CHART 1

CHART 2

CONNECT TWO KNOWN VALUES & READ THIRD AT POINT OF INTERSECTION.
 EXAMPLE: IF $\lambda=600\text{M}$ AND $C=0.00035\text{MFD}$, THEN $L=300\text{MH}$.

CONNECT THREE KNOWN VALUES AS PER KEY, AND READ FOURTH AT POINT OF INTERSECTION.
 EXAMPLE: IF $L=300\text{MH}$, $D=2''$, AND $N=53$, THEN $\ell=1\frac{11}{16}''$

Fig. 100

reading the third at the point of intersection. Thus, connecting 600 meters with .00035 mfd. capacity, gives a line which intersects the inductance column at 300 microhenries. This is the inductance required.

Now the formula for the inductance of a single layer solenoid is

$$L = 0.025 N^2 R^2 1K$$

Where L is in microhenries

N is turns per inch

R is radius of the solenoid in inches

1 is the length of the solenoid in inches

K is the form factor.

K depends on the ratio of length to diameter. Values of K for various values of this ratio are given on page 283 of Bureau of Standards Circular No. 74, for those interested in the various inductance formulas. Obviously the calculation is complicated.

The dimensions of the coil can be found very easily by the aid of chart 2 of Fig. 100, and the copper wire table of Fig. 101. A line is drawn from the common L scale, from $L = 300$ to $D = 2$, intersecting the index line at "e." Referring to the magnet wire table of Fig. 101, we find that No. 28 D. S. C. wire contains 53 turns per inch. Now another line is drawn from this value on the N scale through the point "e" of intersection of the previous line with the index line, until it intersect the 1 scale. This shows that the coil should be wound to a length of 1.7 inches, and the product of N and 1 gives 90 as the number of turns of wire required. The charts can be worked in the reverse direction in exactly the same way, always making sure that the correct pairs of scales are connected together.

To check the minimum wavelength we draw a line from $L = 300$ to $C = 0.00003$ on chart 1 and find it intersects the wavelength line at 180 meters. Actually the minimum wavelength will be higher than this due to the increased effect of the distributed capacity of the coil, the input capacity of the tube, and capacity of circuit wiring at this low wavelength.

This example shows how simple the design of coils becomes, with the aid of the charts. They can be used in many ways, for finding any constant of a coil when all others are given.

It must be remembered that this method of coil design applies only to a single coil of wire isolated in space and connected to a variable condenser. The moment another coil is brought into the vicinity, the conditions change. For instance, if this coil is to be used with an untuned primary coupled to it, it will be necessary to use one or two more turns on it than the number obtained from the charts. This also holds true when a tickler coil is used with it. If the coupling between the various coils is loose, however, there will not be much change in the inductance of the secondary, so no correction need be made. The same procedure applies to the coupling devices used in impedance or tuned plate R. F. amplifiers.

163. PRIMARY COIL: The design of the untuned primary coil presents several difficulties, and in most cases the final design represents a compromise between several factors. Since the function of the primary coil is to transfer energy to the secondary through the medium of its magnetic field, it would seem that best results would be obtained by a large number of primary turns so closely coupled to the secondary coil that all of its lines of force link with the secondary.

This condition would best be met by winding the primary on a form and placing it inside of the secondary, either as a concentrated winding at the center or a distributed winding equal to the length of the coil. If we built a coil in this manner we would find that the tight coupling produces several very serious objectionable effects. A study of this will now be made.

164. **TIGHT COUPLING:** Let coils L_3 and L_4 (Fig. 102) be so arranged that loose coupling exists between them, that is, L_3 is separated from L_4 so that only a small number of its lines of force link with L_4 . If the tuning condenser is varied from zero to maximum capacity, we find the current varies as shown by curve A of Fig. 103, having a maximum value at the resonant point. This curve has a sharp peak if the coupling is sufficiently loose, and the tuned circuit is selective; in fact, it may be too selective.

If the coils are moved closer together to tighten the coupling we might expect that as the field of coil L_3 linking with coil L_4 is stronger, the current in coil L_4 will be greater. This, however, is not the case. The current in L_4 set up by L_3 is in such a direction as to set up a magnetic field opposing the field produced by L_3 (Lenz's Law), and this effect will be stronger the greater the current flowing in L_4 . As the natural frequency of the L_4 tuned circuit is increased from zero to maximum by the variable condenser, we find that as we approach the resonance frequency the current in L_4 *gradually* rises. As the current becomes stronger, the opposing field also increases, correspondingly reducing the effective or inducing field.

As a matter of fact, a point will be reached where the current in L_4 will cease to increase, or actually decrease at the previous resonance point, as shown

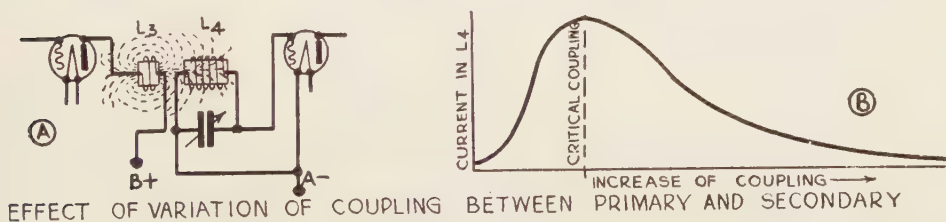


Fig. 102

by curves B, C, and D, in Fig. 103. The closer the two coils are placed together, the more marked will this effect be, as shown by curves B, C, and D, which represent successive degrees of coupling. The double humped curve D represents an extreme condition where there are two resonance points, that is, the same station comes in loud at two points separated on the dial. This of course is due to too light coupling between the primary and secondary coils.

The question now arises as to just what proper value of coupling is necessary for best results. Let us consider L_3 and L_4 (Fig. 102A), situated ten feet apart. Then since there is practically no linking of the magnetic field of L_3 with L_4 , the coils have no effect on each other. If we now bring them together slowly we shall come to a point where the field of the primary links with the secondary inducing

a weak current in it. As the coils are brought closer together more and more of the magnetic field of L_3 links with L_4 , resulting in a gradual increase of current in the secondary. Finally, as the coils are brought still closer, the current in the secondary reaches such a value that it reacts seriously upon the primary, as we have described, causing the *effective* field to be reduced and the current weakened. The point where the secondary current no longer continues to increase as the coupling is tightened is called the point of critical coupling. This is shown graphically in Fig. 102B, where it is seen that as the coupling is increased from zero the current in L_3 passes through a maximum. Therefore for best results the coupling must be adjusted to the critical value. Looser coupling than this results in poor transfer of energy, closer coupling results in poor selectivity, and also results in the secondary condenser tuning the primary coil through the agency of the reversed magnetic

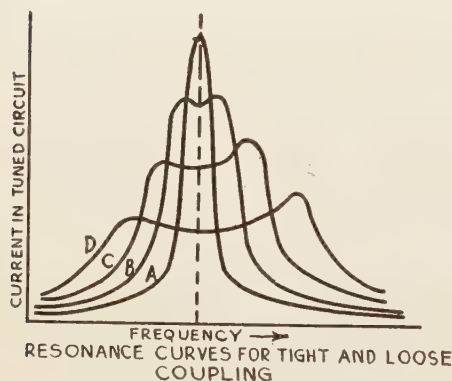


Fig. 103

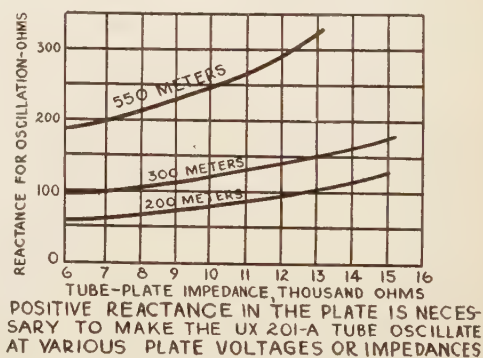


Fig. 105

field. This tuning of the primary results in oscillation tendencies similar to those in the tuned plate regenerative set (see Article 116). (Notice that the selectivity of coil L_3 is governed by something else besides its resistance; namely, the tightness of coupling.) Now that we have found that there is a critical value of coupling which is desirable, the next problem is to design the primary coil to produce this coupling.

165. **PRIMARY IMPEDANCE:** The coupling depends not only on the physical spacing relation between the primary and secondary, but also on the number of primary turns. It is evident that we have two variables. Either a small number of primary turns can be placed close to the secondary, as in Fig. 104A, a medium number of turns can be placed at a small distance from the secondary, as in Fig. 104B, or a large number of turns can be placed at a greater distance from the secondary, as in Fig. 104C. In each case the coupling may be the same, but which is best? This is answered by considering the plate impedance of the tube. It is generally known that for maximum amplification from a three-electrode vacuum tube, the impedance of the external plate load must be equal to the internal plate impedance of the tube. For the 201A tube working as

an R. F. amplifier with 90 volts on the plate and — 4.5 volts grid bias, this is about 12,000 ohms. It is impractical to use a primary coil having enough turns to produce this high impedance, for then the reactive voltage across it would tend to cause violent feedback through the plate-grid capacity of the three-electrode tube, as explained in a previous chapter.

Laboratory measurements have shown that in practical amplifiers using 201A type tubes, the tubes go into violent oscillation with an inductive plate load much smaller than that necessary for optimum amplification. This is indicated by Fig. 105, which shows the curves taken at three different frequencies (corresponding to

200, 300, and 550 meters) between the values of plate reactance necessary to produce oscillation and the tube plate impedance. Taking the 300-meter curve, it will be seen that the tube will oscillate with the given circuit characteristics with a positive plate reactance of *less than 100 ohms*, while 6,500 ohms is necessary for a primary which will match the plate impedance of the tube. The curves also show that as the plate impedance is

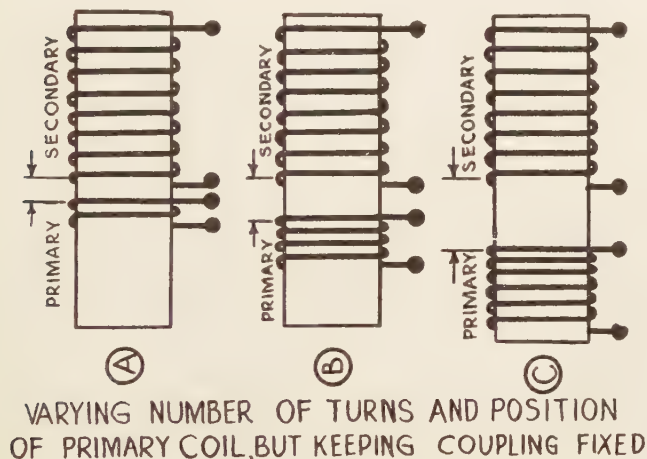


Fig. 104

increased by decreasing the plate voltage, the amount of plate load reactance necessary to produce oscillation is also increased. (This is why oscillation control by a variable high resistance in the plate circuit is effective.) These curves were compiled by Mr. Fred J. Marco.

Also, such a large number of turns, self-tuned by their distributed capacity, would tend to tune the plate circuit, further increasing the oscillation tendency. Here is where the compromise is effected. The number of primary turns and their relative location with respect to the secondary are governed in practical work by the circuit conditions. In multistage stabilized R. F. amplifiers where there is always some regeneration present, the number of primary turns on the R. F. transformers of 2 or 3 inches diameter is kept down to around 10 or 15 to keep the plate reactive voltage down, and they are placed from $\frac{1}{4}$ to $\frac{1}{2}$ inch from the filament end of the secondary for proper coupling. On a one-stage R. F. amplifier a greater number of primary turns can be used. In perfectly neutralized bridge circuits, obviously the greatest number of turns can be used with high gain in both the transformers and tubes.

It is evident from this detailed discussion that the final design of the primary coil of the interstage tuned R. F. transformer must necessarily be a compromise between selectivity, gain, oscillation tendencies, simplicity, and cost.

Primary windings can be made of small sized wire such as No. 28 or 30, since even a few hundred ohms resistance in the primary is only a small percentage of the 10,000 to 20,000-ohm plate resistance of the tube, and is therefore negligible.

166. BROWNING DRAKE COIL: Browning and Drake have shown that in a receiver containing one stage of tuned R. F. amplification followed by a regenerative detector, maximum R. F. amplification can be secured by employing an interstage coupling coil constructed as shown in Fig. 106. This is known commercially as the Browning-Drake coil or Regenaformer. A 199 type of tube is used as the R. F. amplifier because it has smaller G-P capacity than the 201A type and hence presents less oscillation difficulties. It was reasoned that the necessity is for a primary of plenty of turns, with little surface and so compact that its capacity relation to the secondary is a minimum. This capacity is often bothersome since it helps feed-backs and has the effect of adding to the difficulty of neutralization when a sufficiently high impedance in the R. F. tube plate circuit

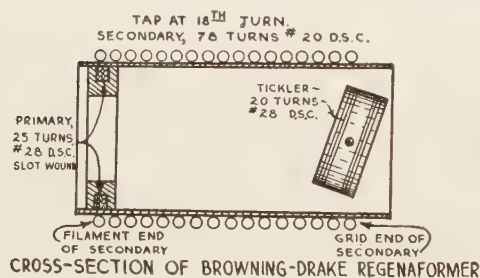


Fig. 106

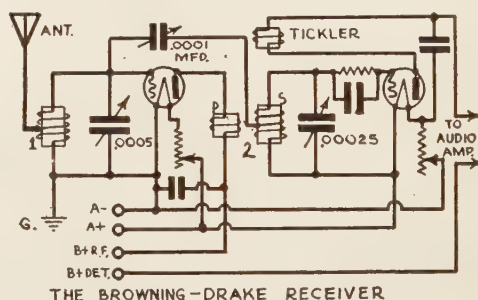


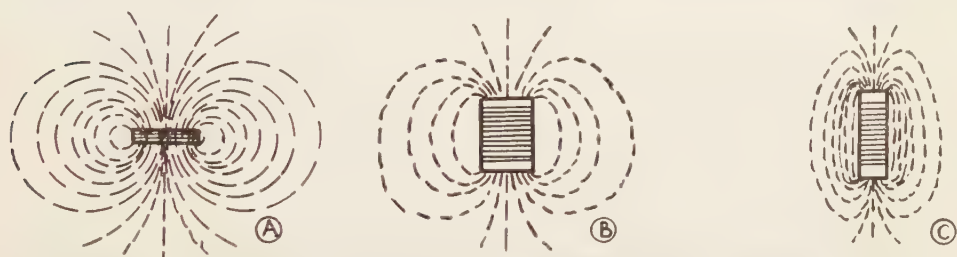
Fig. 107

causes oscillation. The reduction of the capacity effect between primary and secondary also increased the amplification, since this capacity causes induced currents in the secondary which are *opposite in phase* to the currents caused by electromagnetic induction.

The primary has about 25 turns of No. 28 D. S. C. wire wound in a narrow slot ($\frac{1}{8}$ by $\frac{1}{8}$ inch) of a tube placed inside of the secondary directly under the filament end of the transformer as shown in Fig. 106. The result was the production of a single stage of R. F. amplification of unusual sensitivity followed by a regenerative detector. Very good results have been obtained with this set. The neutralized R. F. tube also acts as a blocking or *muffler tube* to prevent radiation from the antenna when the detector is set at the oscillating condition. This is true because the oscillating current cannot feed from the plate to the grid circuit of the neutralized R. F. tube. Such a muffler tube is a necessity with a regenerative detector, if squealing and interference is to be prevented. The Browning-Drake circuit is shown in Fig. 107. The antenna is coupled directly to the first tuned coil for maximum energy transfer. One weak point in this set has been its lack of extreme selectivity, making interference troublesome when used near large broadcasting stations. This broad tuning is probably due mostly to the tight coupling in the Regenaformer.

167. INTERSTAGE COIL COUPLING: As we build R. F. transformers and amplifiers which approach closer and closer to the maximum efficiency, the unavoidable stray couplings in the set tend to increase the feedback and throw the set into oscillation. Even if the tube capacities are properly neutralized, any stray couplings in the set are able to feed energy back from one stage to another, causing oscillation. For perfect balancing, neutralization or stabilization these must be eliminated. This factor is often overlooked in sets, where, despite elaborate precautions to eliminate tube feedback by neutralization, bridge circuits, etc., persistent oscillation tendencies are present. The stray couplings are of three kinds, magnetic, capacity, and resistance coupling between stages; and the designer or set builder must use every resource to overcome them.

The wiring of the set should be so laid out as to minimize capacity and inductive feedback, by keeping all *grid* and *plate* connections far apart, and if they must be run close, at right angles to each other. Coupling between the



SHOWING HOW SOLENOID COIL PROPORTIONS AFFECT MAGNETIC FIELD

Fig. 108

successive tuning coils can take place through the medium of their magnetic fields. This is by far the most prevalent form of coupling, but fortunately it can be almost entirely eliminated by proper design.

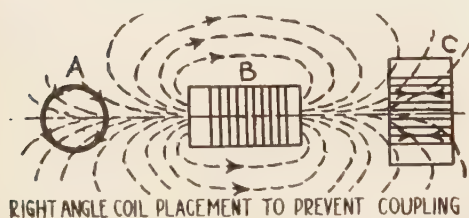
The first precaution to eliminate magnetic coil coupling is to use coils having limited external magnetic fields. The torroid, D coil, binocular coil, etc., possess this characteristic, but these coils all have a much greater R. F. resistance for a given inductance than the simple solenoid coil.

168. COIL PROPORTIONS: The shape of the magnetic field around a solenoid coil changes as the proportions of the coil change, as shown by Fig. 108. "A" shows the field around a short coil of large diameter. The field is nearly circular in shape, and extends out a large distance on all sides of the coil, obviously very good for interstage feedback coupling. "B" shows a coil slightly longer than it is wide. The field is slightly elliptical in shape and does not extend out as far on the sides of the coil as the other. "C" shows a long coil of small diameter. The field is very elliptical and does not extend far out from the coil. This is obviously the type of coil we are looking for. Many of the commercial sets employ coils of this type having a diameter of about 1 inch and length of about 2 inches. They are wound with about No. 30 enameled wire space-wound in a shallow spiral groove machine-cut in the coil form.

169. PLACEMENT OF COILS: Even if coils whose external magnetic

field is limited are used, coupling can be further guarded against by mounting the coils so that the lines of force *cut through them at right angles* to the axes of the coils. This can be done in two ways.

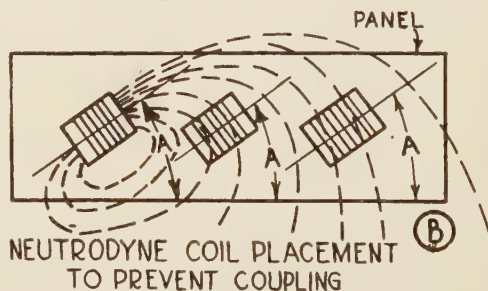
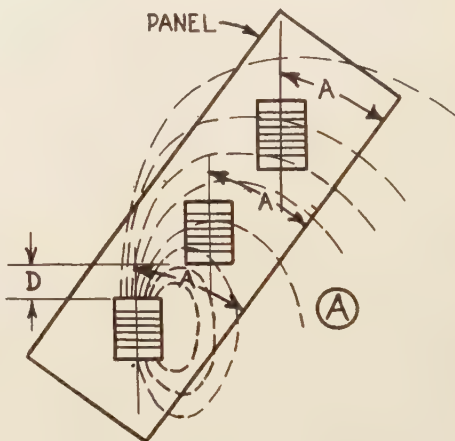
If the coils are all mounted with their axes lying in the same straight line, and turned so every coil is at right angles to every other coil, no coupling will exist. Fig. 109 shows this relation for three coils. Consider the magnetic field of



Left: Fig. 109

Right: Fig. 110

Coil B having a direction as shown by the arrows, at some particular instant. It links with coils A and C. Any line of force approaching the coil from the right cuts the coil twice and sets up a current in each part. These currents are in opposite directions as shown by the arrows, and since they are equal, they neutralize each other. Hence there is no coupling in A. Similar reasoning holds for coil C, where the direction of the induced currents is shown. This right-angled placement of coils is simple and effective and is used extensively in tuned R. F. sets.



Another method is by placing the coils parallel to each other, but at such distances apart that the lines of force of each coil cut through the other coils at right angles to the axis, thus producing equal and opposite currents in both halves of each turn, which neutralize each other. This is shown in Fig. 110. If the coils are mounted on a panel, in the manner shown in Fig. 110A to save space, it is found that the coils make angles A with the base of the panel. If this panel is shown in a horizontal position as in Fig. 110B, you will probably recognize the familiar neutrodyne arrangement.

Obviously the angle A at which the coils must be placed, and the distance D between them, are not constant factors, but vary with the physical proportions of the coils, since the shape of the magnetic fields also vary with these. Conse-

quently, although 54.7 degrees was recommended for the no-coupling angle A in the old neutrodyne sets, it does not follow that this angle is correct when coils of different size are used. The angle must be determined for the particular coils used. This makes the right-angle placement, discussed previously, more practical for ordinary use.

170. **SHIELDING:** Magnetic and capacity couplings between R. F. stages are also effectively reduced or entirely eliminated by inclosing the various stages in closed grounded metal shields made usually of copper or aluminum. Any stray magnetic fields are absorbed by the metal (setting up eddy currents in the metal). However, shielding introduces resistance into the tuned circuits due to the losses, unless great care is taken in allowing proper clearance between the coils and the shields. Copper is preferable as a shielding material since it has a low electrical

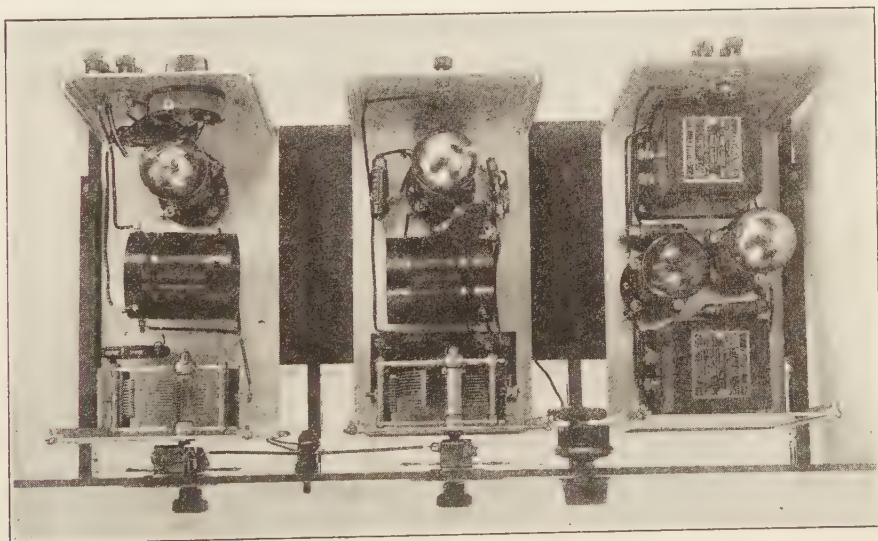


Fig. 111. Receiver With Aluminum Shield Cans Partially Removed

resistance and therefore absorbs the stray fields effectively. It can also be soldered easily.

Copper about $1/32$ of an inch thick (24 or 26 gauge) should be used. Sheet aluminum, since it has a higher resistance than copper, should be about $3/64$ of an inch in thickness. If brass is used, it should be at least $1/8$ inch thick.

Aluminum stage shields about .08 inch thick are popular because they are comparatively cheap and can be obtained in collapsible form, making them easy to install when constructing a set. The practical use of shields of this type is shown in the receiver photographs of Fig. 111 and 112.

The shields are usually all grounded to the minus side of the filament, and usually serve as the common "A—" lead. All holes necessary for instrument shafts, wiring, etc., should be as small as possible, since the shielding effect can be totally spoiled by a few open holes. Where wires are brought out through the shields, it is a good plan to use small hard rubber bushings to prevent abrasion of the insulation with resulting short circuits.

One effect accompanying the shielding of a coil is shown in Fig. 113. The coils of wire and the metal can form the plates of a condenser. This is a constant capacity and acts the same as the distributed capacity of the coil. It reduces the

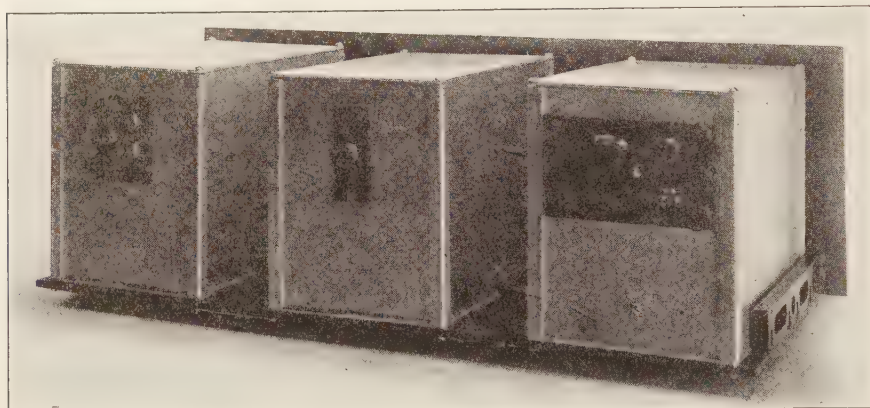


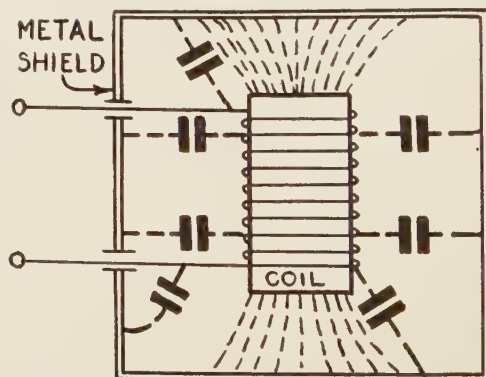
Fig. 112. Receiver of Fig. 111 With Shields in Place

effective tuning range, and must be compensated for in the design of the coil. This can be done by using variable condensers having a higher maximum capacity



Fig. 112A. Shielded R.F. Plug-in Coil

Right: Fig. 113



CAPACITY ACTION OF SHIELD
AROUND AN R.F. COIL

(giving greater maximum capacity variation). Also, since part of the magnetic field of the coils is absorbed by the shields, resulting in a reduction of inductance of primary and secondary coils, it is sometimes necessary to employ a few more secondary turns with a given tuning condenser than would ordinarily be necessary.

Shielding is rarely necessary in audio frequency amplifiers, unless a large number of stages of amplification are used. Its main advantage *when properly applied* in R. F. circuits is that in eliminating the stray capacity and inductive feedback between the various stages, there is only the tube capacity to neutralize and this is practically independent of the frequency. As a consequence, almost

perfect neutralization is obtainable and it is more uniform throughout the frequency range. Since oscillation tendencies are almost eliminated, higher amplification per stage is made possible by use of R. F. transformers giving the largest gain and working nearer the oscillation point. Since self-oscillation is better controlled with shielding, it is possible to use a greater number of amplifying stages, with increased sensitivity. Unless small coils are used it is almost impossible to secure a perfect balance or neutralization in bridge circuits or neutrodynes, if shielding is not employed, unless these coils are spaced very far apart, making the set bulky.

Shielding should not be used indiscriminately, since it increases the cost and complicates the construction of a set, and in some cases will result in no practical gain. In fact, it may even be harmful if not applied properly.

With ordinary tubes in sets using one stage of R. F. amplification and regenerative detector, since most of the energy is confined in the detector circuit, with comparatively small R. F. currents flowing in the R. F. amplifier, shielding is usually unnecessary if the coils are kept at right angles and a fair distance apart. In exceptional cases, a grounded plate shield placed between the coils will be all that is necessary for shielding. With two stages of tuned R. F., shielding is not usually required, if small coils placed at right angles, a reasonable distance apart, are used, and if wiring is done carefully. A small grounded plate shield between the transformers will usually suffice in exceptional cases. In sets employing three or more stages of R. F. amplification, it is almost always necessary to completely shield the individual stages of the entire R. F. amplifier, if high amplification per stage is to be obtained. All "A" and "B" power supply leads should be properly choked and bypassed to prevent R. F. currents from the various stages from passing into the power supply device and causing interstage coupling there due to the various impedances encountered.

Wiring in a shielded set should be laid out carefully. Plate and grid leads and connections to neutralizing coils and condensers must be removed as far as possible from the metal, in order to minimize their capacity to ground, and thus minimize detuning effects. Grid and plate neutralizing connections that must be run from one shielded compartment to another should be carefully insulated from, and not run parallel to, the shields. Fig. 114 shows how shielding is applied to a 3-stage R. F. amplifier and detector with bypassing condensers, etc.

171. COUPLING IN B SUPPLY: When a receiver utilizes a single source of plate voltage for more than one stage (as is almost always the case) coupling between stages may take place through the resistance of this power source, as shown in Fig. 115A. New "B" batteries have a very low internal resistance, but when they become old and discharged their internal resistance may increase to as much as 1,000 ohms. This is the resistance of the active material between the zinc cylinder and carbon rod of each of the small dry cells units. In a 45-volt "B" battery there are 30 of these cell units connected in series, so the total internal resistance is equal to 30 times the resistance of each unit. "B" power packs all use some form of resistance for a voltage dividing device, and the plate currents of the various tubes must flow through this resistance, which often amounts to several thousand ohms (see chapter on "B" power units). In either case the internal resistance may be considered as a resistance R (Fig. 115A) in

series with the power supply device (which is here shown as batteries for simplicity).

The resistance R is included in the plate circuit of both tubes A and B. The plate current of either of the tubes varies somewhat in the manner shown in Fig. 115B, and this current will readily be seen to be equivalent to two currents, one a steady direct current, Fig. 115C, and the other an alternating one, Fig. 115D. This steady current flowing through resistance R produces a steady voltage drop in which we are not interested. The alternating current component of tube B flowing through resistance R produces a varying voltage drop in which we are not interested. The alternating current component of tube B flowing through R produces a varying voltage drop across R , thus varying the effective voltage ($E-e$), applied to the plate of tube A, varying its plate current. This variation is transferred to secondary coil S by the primary P so that the result is a feedback from the plate circuit of NB to its grid circuit. This same action occurs among the various other tubes in the receiver.

172. **R. F. CHOKES:** Obviously the cure for this is to keep the varying current out of the "B" power device E and return it directly to the minus leg of the respective tube filament. This is accomplished by the connection of Fig. 115E, where an R. F. choke has been connected in each plate lead between the primary and the current source, and a bypass condenser "C" connected directly to the negative leg of the filament. The R. F. choke consists of a small air core inductance coil of between 40 and 100 millihenries *wound so it has a very small distributed capacity*. Such a coil has a very large impedance at radio frequencies so that it effectively blocks the passage of radio frequency currents. At the

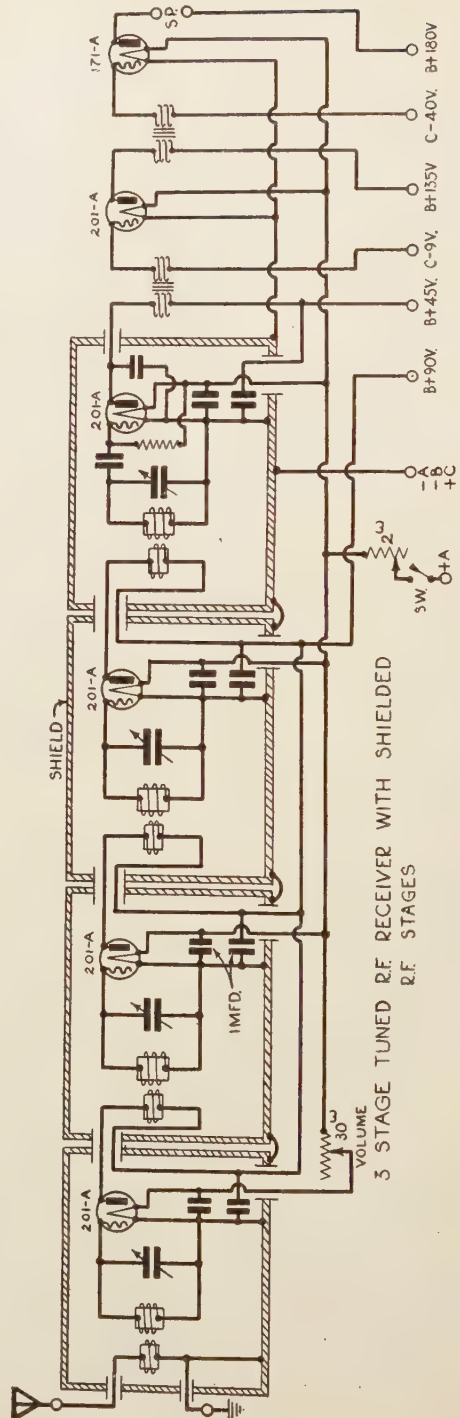


Fig. 114

same time its resistance to a direct current is low. The condenser "C" is of sufficiently large capacity to form a path of low impedance for the R.F. currents so that they return directly to the filament and complete their circuit inside the tube, but no direct current can flow through it. The choke and by-pass condenser should be connected as near to the end of the primary coil as possible and the by-pass circuit should be kept short, and returned directly to the filament, of the *same* tube whose plate current is being by-passed in order to preclude the possibility of R. F. coupling between unnecessary lengths of wire due to R. F. currents therein. We have studied the use of the choke coil and by-pass condenser in connection with regenerative detectors, Fig. 71, where they should always be employed.

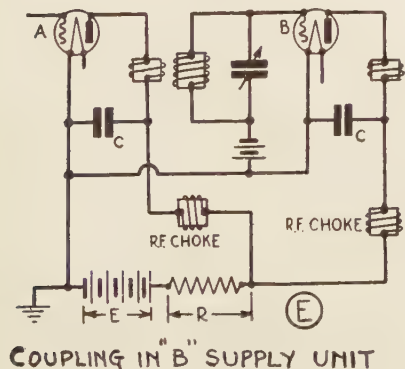
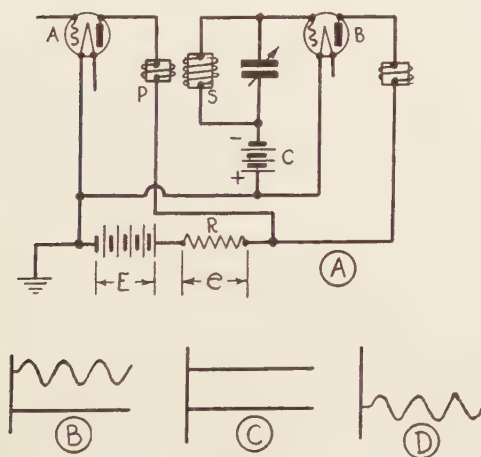


Fig. 115

R. F. choke coils are usually wound helically or have their windings divided into three separated sections (Fig. 117) in order to keep the distributed capacity as low as possible, for distributed capacity lowers the choking effect to R. F. currents. In this latter type the narrowest section should be connected to the high potential end of the circuit; in Fig. 115E it would go to the end of the plate coil. The general rule is that whenever a choke is used, there must be a by-pass condenser of *low impedance* to direct the unwanted currents to the place where they will do no harm.

173. BY-PASS CONDENSERS: This leads us to the question of what size by-pass condensers to use consistent with proper by-passing action and low price. Since the capacitive reactance of a condenser varies inversely as the frequency, the selection depends on the frequency of the currents to be by-passed. The lowest R. F. in the broadcast range is 500 kilocycles (600 meters). The table of Fig. 116 shows how the reactance of various size condensers varies between 1,500 kilocycles (200 meters) and 500 kilocycles (600 meters).

From these values it is evident that a condenser of from .006 mfd. to 0.1 mfd. has the necessarily low impedance for by-passing the R. F. currents. It must be remembered that in regenerative detectors (Fig. 71) the condenser connected from the R. F. choke to the filament should not be larger than .001 mfd., or by-passing of the upper audio frequencies will result.

Fig. 117 shows an R. F. choke of subdivided winding, with a fixed .006 mfd. by-pass condenser. Notice that the beginning and end terminals of the choke are effectively kept apart by this construction. R. F. chokes and by-pass condensers should be employed in every stage of R. F. amplifiers and detectors when necessary. The proper way of connecting them is shown in the circuit diagrams of the following chapter.

174. **CONSTANT R. F. COUPLING:** A study of the coupling existing between the primary and secondary of an R. F. transformer having a fixed primary reveals the fact that the energy transfer is not constant over the wavelength band.

COND. CAP. IN MFD.	CONDENSER REACTANCE IN OHMS AT VARIOUS FREQUENCIES								
	60 CYCLES	100 CYCLES	250 CYCLES	500 CYCLES	1,000 CYCLES	10,000 CYCLES	100,000 CYCLES	1,000,000 CYCLES	2,000,000 CYCLES
.0001	26,660,000	16,000,000	6,400,000	3,200,000	1,600,000	160,000	16,000	1,600	860
.0005	5,332,000	3,200,000	1,280,000	640,000	320,000	32,000	3,200	320	160
.001	2,666,000	1,600,000	640,000	320,000	160,000	16,000	1,600	160	80
.002	1,333,000	800,000	320,000	160,000	80,000	8,000	800	80	40
.006	444,000	266,700	106,700	53,300	26,700	2,670	267	27	13
.01	266,600	160,000	64,000	32,000	16,000	1,600	160	16	8
.1	26,660	16,000	6,400	3,200	1,600	160	16	1.6	0.8
.5	5,332	3,200	1,280	640	320	32	3.2	0.32	0.16
1	2,666	1,600	640	320	160	16	1.6	0.16	0.08
2	1,333	800	320	160	80	8	0.8	0.08	0.04
4	666	400	160	80	40	4	0.4	0.04	0.02
6	444	267	106	53	26	2.6	0.26	0.026	0.013

Fig. 116

The induced R. F. voltages in the secondary turns are proportional not only to the strength of the primary field, but also to the rapidity with which that field alternates. Thus at the short waves, the R. F. alternations are much faster than at the long waves, and the induced R. F. voltages will therefore be much greater at the short waves around 200 meters than is the case when receiving stations around 500 meters. If such a circuit is made non-oscillating at 200 meters it has little sensitivity at 500 meters. If it is made sensitive at 500 meters by working near the oscillation point, it usually oscillates violently at lower wavelengths.

Several schemes have been advanced to remedy this defect. In one, the Lord system, the primary coil is moved away from the secondary as the condenser is tuned to the shorter wavelengths. This is accomplished by a cam on the condenser shaft which acts on a follower attached to the primary coil. It is easily seen that the primary field, being removed from the secondary field at the shorter waves, cuts a smaller number of secondary turns and thus induces less voltage.

In another, the King system, the primary is mounted on the condenser tuning shaft by an adjustable bracket and in such relation to the secondary coil that as

the condenser is tuned to the low wavelengths the primary is rotated more and more at an angle with the secondary, thus loosening the coupling. In both these systems the plate load impedance remains substantially the same.

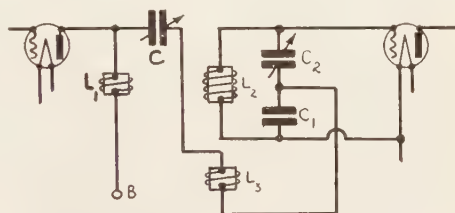
An arrangement credited to K. Hassel and used in Zenith receivers consists of taking a portion of the primary coil and mounting it on the condenser shaft so that it rotates inside of the secondary coil, in such a manner that the rotating portion of the primary coil opposes the coupling from the fixed portion at the low waves and adds to the coupling at the high waves. In this way the primary-secondary coupling is varied with change of wavelength and the impedance of the tube plate load is varied to keep it just below the critical value.

175. **LOFTIN-WHITE CIRCUIT:** An electrical circuit method of automatically securing equal voltage transfer at all wavelengths is credited to Loftin and White. This is based on the fact that the reactance of a condenser increases



Fig. 117. Fixed By-Pass Condenser and R. F. Choke Coil

Right: Fig. 118



LOFTIN-WHITE CONSTANT COUPLING CIRCUIT

as the frequency decreases and that the impedance of an inductance decreases as the frequency decreases (exactly opposite). The circuit of this system, one stage of which is shown in Fig. 118, has its inductances and capacities so connected that there is both inductive and capacitive coupling. The values of the inductances and capacities are so adjusted that as the reactance of say the inductance starts to drop off, the reactance of the condenser increases, and vice versa, so that actually the coupling resistance remains constant for all wavelengths. Consequently after the associated circuits have once been adjusted to prevent oscillation, there is no change in either the amount of selectivity, sensitivity or regeneration, at any wavelength. By proper adjustment the set may also be made to oscillate at either the high or the low wavelengths.

In Fig. 118 it can be seen that inductive coupling is obtained through coils L_2 and L_3 , while capacitive coupling is furnished by the condensers C and C_1 . Coil L_1 is an R. F. choke which prevents the leakage of any R. F. currents into the "B" battery circuit, and makes them all go through L_3 , through C_1 to the filament, while C is a phase shifting condenser which is employed for the purpose of shifting the phase of the R. F. plate current (as explained in the case of the Phasatrol).

Mutual inductance is less effective for transferring energy at the higher wavelengths than at the shorter ones. Mutual capacity behaves in an opposite manner. Suppose that the set is tuned to a low wavelength and all constants are adjusted to keep the receiver at maximum efficiency. Now suppose it is tuned to a higher wavelength. The energy transfer from L_2 to L_3 by inductive coupling decreases. Also as the tuning condenser C_2 is increased in capacity for tuning to the longer wavelength, its reactance decreases, and the voltage drop across it

decreases. Therefore, there is more voltage across C_1 proportionately, and hence more current is fed to the tuned circuit by the capacitive coupling, offsetting the effect of the decreased energy transfer by magnetic induction.

Because this circuit contains both inductive and capacitive couplings and the phase-shifting reactance, it contains three elements that can be adjusted to offset undesired inductive and capacity couplings and stray feedback. This works out so that little shielding and sometimes none at all is required, where it would be reasonable to expect that shielding would be necessary. Of course, L_3 , L_1 , L_2 , C , C_1 and C_2 must all be properly proportioned and related to each other to produce these desirable results. If C_2 is a 0.0005 mfd. tuning condenser, C_1 can be a 0.004 mfd. fixed condenser, and C a variable condenser having a maximum capacity of about 0.001 mfd. This circuit is not used much at present due to the difficulty of adjusting all these parts when the receiver is built. It is unsuited to quantity production methods of manufacture.

The design of R. F. amplifiers has undergone radical changes during the past few years. A more thorough understanding of the exact actions going on in the tubes themselves, and common sense design applied to the interstage coupling devices has resulted in the production of R. F. amplifiers of remarkably high gain and stability. Furthermore these have been designed to permit of their successful manufacture by modern quantity production methods without costly special parts.

The introduction of the screen-grid type of tube (described in Chapter 17) has also resulted in practically a new trend in R. F. amplifiers. The high amplification factor of this type of tube combined with its extremely high plate impedance (See page 68), has made it necessary to design special interstage coupling devices to bring out its full possibilities and advantages. The high amplification produced in each stage makes it very essential that every precaution be taken in the design and layout of the parts and wiring to prevent capacitive or inductive feed-back from stage to stage with consequent violent oscillation effects. Grid leads are kept as short as possible and isolated from the other wiring; and usually each R. F. stage consisting of screen-grid tube, coupling device and tuning condenser is enclosed in a grounded aluminum shield can. In other cases the coupling coils are shielded individually. Most modern R. F. coils are being wound on Bakelite or similar tubing of small diameter (around one inch), in order to make them more compact. These coils also have the advantages of having an external magnetic field which does not spread out very far, and therefore can be easily shielded with metal shields of moderate size without introducing too much objectionable eddy current loss in the shielding.

Precision coil winding machinery has been developed to wind the coils so they are turned out by the thousands, with electrical constants suitably uniform. Enamel covered copper wire is used extensively on account of its obvious advantages of being handled without damaging by finger marks, and being unaffected by atmospheric moisture.

REVIEW QUESTIONS.

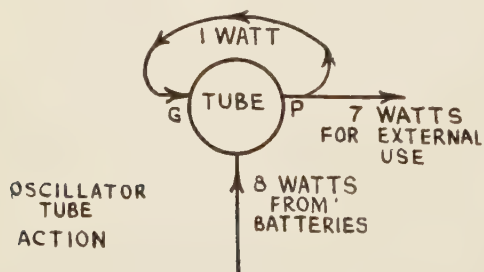
1. State the advantages of tuning the R.F. stages.
2. Explain how tuning produces selectivity.
3. Explain how resistance in the tuned circuit decreases the signal strength and the selectivity.
4. What is meant by "cutting sidebands" and what causes this action?
5. Explain how selectivity is increased by increasing the number of tuned R.F. stages.
6. What is meant by the distributed capacity of a coil? What is the objection to high distributed capacity in a tuning coil? How may distributed capacity be kept low?
7. Describe several types of inductance coils and state the advantages and disadvantages of each.
8. How may the coupling between the primary and secondary of a coil be tightened, loosened?
9. What is the special feature in the design of the Browning-Drake regenerative coil?
10. How does a stage of neutralized R.F. amplification ahead of a regenerative detector prevent oscillation radiation from the antenna?
11. How may coils be placed to prevent inductive coupling between them?
12. What is the purpose of shielding in R.F. amplifiers and how does shielding accomplish it?
13. What materials are suitable for shielding?
14. Explain how R.F. coupling can take place in the "B" supply unit, and how it may be avoided.
15. What is an R.F. choke, by-pass condenser?
16. Describe two methods of producing constant R.F. coupling over a definite waveband.

CHAPTER 13.

OSCILLATORS, MODULATORS, SUPER-HETERODYNE.

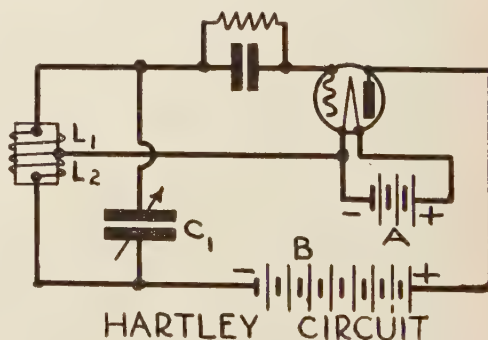
V. T. OSCILLATORS — TICKLER FEEDBACK — HARTLEY CIRCUIT — PORTABLE OSCILLATOR — MEISSNER CIRCUIT — COLPITTS CIRCUIT — ARMSTRONG CIRCUIT — MODULATION — POWER OUTPUT ABSORPTION MODULATION — GRID MODULATION — MODULATED R. F. TEST OSCILLATOR — BROADCASTING STATION — AUDIO OSCILLATOR — SUPER-HETERODYNE — FREQUENCY CHANGING — DOUBLE OSCILLATOR SETTING.

176. VACUUM TUBE OSCILLATORS: In Chapter 11, the phenomenon of oscillation occurring when energy is fed back from the plate to the grid circuit of a three electrode vacuum tube was studied. This should be reviewed at this time. Various oscillator circuits will now be described, since they are used in many ways. Oscillator tubes are used in broadcasting stations to generate the high frequency carrier currents, and are used in the superheterodyne type of receiver. They are employed for generating both R. F. and A. F. currents for experimental work, since they can be designed to produce currents varying from a few cycles per second to several million. The testing of R. F. circuits requires an R. F. oscillator, and testing of audio units and sound reproducing apparatus requires a source of constant or variable audio frequency current. The frequency characteristics of the oscillator must be accurate and reliable over a period of time, and the load coupled to the circuit must not change the frequency in any manner.



Left: Fig. 119

Right: Fig. 120



In an oscillating vacuum tube, part of the varying plate current is fed back to the grid, inducing an alternating current voltage in the grid circuit. This is then amplified by the tube. The limit of amplification is reached when the grid voltage swings the whole length of the characteristic curve of the tube, for at the

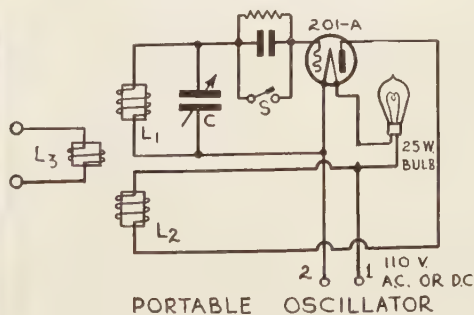
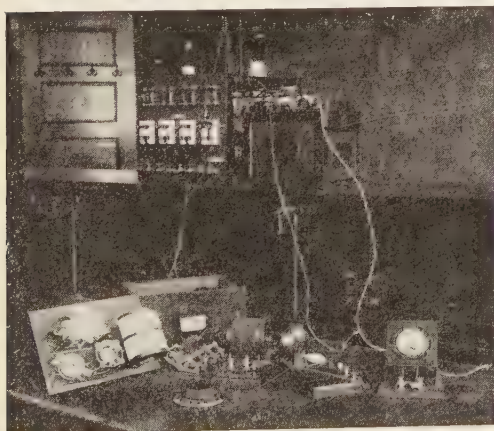
ends of the curve any increase in grid voltage has little or no effect in increasing the plate current (see Fig. 51B).

To consider a case with simple figures, if one watt of energy is all that is required in the grid circuit to work the tube to capacity, and to set into motion eight watts of energy in the plate circuit, then by suitably coupling an external circuit to the plate circuit we can absorb seven watts from it for any purpose we desire, and feed one watt back to the grid circuit to be used in sustaining the oscillations. (The extra power comes from the "B" battery). This is the principle of the oscillator, and is shown in an elementary way in Fig. 119. It is evident that the oscillator really depends upon the amplifying properties of the tube.

There are several common oscillator circuits, each one having certain desirable characteristics which make it suitable for a certain use, all working on the principle of feeding energy back from plate to grid. They are named after the men who first developed them.

177. TICKLER FEEDBACK: We saw in Chapter 9 how a vacuum tube could be made to oscillate by means of a tickler feedback. (See Fig. 67). This is a simple circuit. As the feedback is increased, the circuit goes into oscillation, the frequency of oscillation being determined by the frequency to which the grid circuit is tuned.

178. HARTLEY CIRCUIT: Fig. 120 shows a simple Hartley circuit. Here coils L_1 and L_2 are really one coil with a center tap. The whole coil is tuned by C_1 . A slight change in plate current flowing through the plate coil L_2 . (as when the circuit is closed at starting) sets up a varying magnetic field which induces a similar current in grid coil L_1 , thus producing feedback. This is somewhat similar to the tickler feedback method. Fig. 121 (left) shows a Hartley R. F. oscillator used for school laboratory experiments on R. F. circuits. The associated



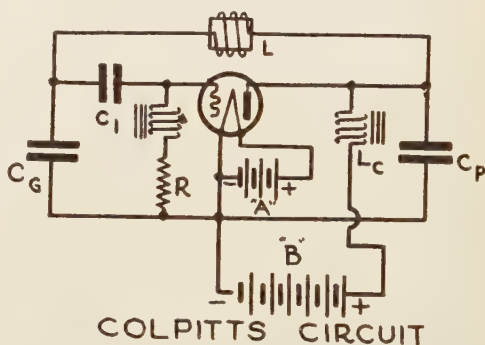
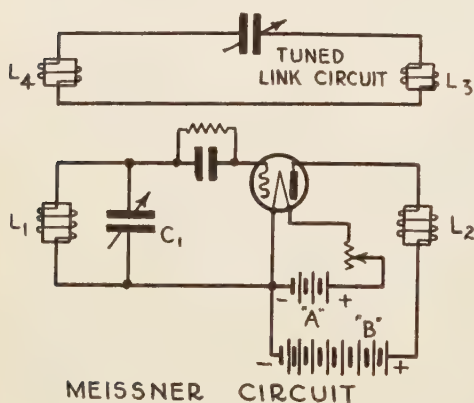
Above: Fig. 122

Left: Fig. 121. Hartley R. F. Oscillator and R. F. Measurement Apparatus

apparatus used for the experiments are shown at the right. Notice the simplicity of construction and wiring of the oscillator.

Hartley oscillators have a tendency to stop oscillating when C_1 reaches a certain critical value.

179. PORTABLE OSCILLATOR: Fig. 122 shows the circuit for a simple and useful portable R. F. oscillator with fixed tickler, designed to operate directly from the 110 volt A. C. or D. C. lighting mains without the need for any batteries. A 25 watt electric light bulb is put in the filament circuit of the 201-A tube to reduce the 110 volts down to five volts for the filament. The plate gets the full 110 volts. Notice that the grid return of the tube is connected to the opposite side of the 110 volt line from the plate return. Coils L1 and L2 can be wound on a single piece of 3" diameter tubing $3\frac{1}{2}$ " long. L1 consists of 43 turns of No. 26 D. S. C. wire and L2 (spaced $\frac{1}{4}$ " from L1) consists of 40 turns of the same size wire, both coils being wound in the same direction. C1 has a maximum capacity of 0.0005 mfd. It should be a straight line frequency condenser if the oscillator is to be calibrated in kilocycles, or a straight line wavelength condenser if it is to be calibrated in meters. If direct current is used, the oscillator will only function when terminal No. 1 is connected to the positive side of the line. The tuning range is from about 200 to 600 meters. A unit of this type is invaluable to



Left: Fig. 123

Right: Fig. 124

the professional set builder, repair man, and school laboratory since there are no batteries to be maintained. The high frequency currents can be transferred to a circuit by inductive coupling by bringing the oscillator coil near a coil or loop of wire in the circuit. Another way is to wind one or two turns of wire L3 around the oscillator coil, running the ends to the place desired (Fig. 122). When switch S is closed it short circuits the grid leak and condenser, and the unit acts as a pure R. F. oscillator. With S open, the R. F. current is modulated so that it can be heard if phones are used. The pitch of the A. F. note can be lowered by making the grid condenser of larger capacity. It can also be controlled by using a variable grid leak. The theory of this modulation effect is simple. The grid charge cannot easily leak off the condenser due to the high resistance of the leakage path, and therefore it has to build up a certain voltage before it can overcome this resistance. This process repeats itself and takes place at a rate dependent on the resistance of the leak. The higher the resistance the lower the frequency of the interruption and vice versa.

The oscillator can be calibrated by means of a receiving set and several broadcasting stations whose wavelength or frequency are known. These calibrating stations should be well separated, to cover the tuning range of the oscillator.

Carefully tune in a high wave station on the receiver. Set the oscillator going, place it near the regenerative detector, and tune it until the audio whistle coincides with the carrier wave of the station. It is best to do this between programs when the carrier is clear. A high pitched heterodyne squeal will be received when the oscillator is on either side of the true beat note of the station. The oscillator should be tuned to a point right between these two heterodyne squeals to the point where these disappear and only the beat note and the program from the station can be heard.

Then the oscillator is working exactly at the frequency or wavelength of the station. The setting of the oscillator condenser dial should be noted and the wavelength of the station looked up and noted next to it. Now tune in stations of successively lower wavelengths and repeat the process until the full range of the oscillator has been calibrated. This is a simple method for calibrating any R. F. oscillator.

180. **MEISSNER CIRCUIT:** In the simple Meissner circuit (Fig. 123) energy is absorbed from the plate coil L2 by the coil L3, placed in inductive relation to it. This sends current around the tuned link circuit into L4. L4 induces a current back into grid coil L1, thus completing the feedback. We now have two tuned circuits, and both must be tuned to the same frequency to make the tube oscillate.

181. **COLPITTS CIRCUIT:** Fig. 124 shows the Colpitts circuit, which uses capacitive coupling to feed energy back from plate to grid. The plate voltage is applied in parallel through a choke coil L_c . The frequency generated is largely determined by the capacity of C_g and C_p in series, and L . The heavy oscillatory currents occur in this circuit. A slight increase in the plate current through the choke coil (as when the circuit is closed at starting) will cause the voltage of the plate with respect to the filament to drop, due to the reactive voltage drop through the choke. This makes the right side of C_p minus with respect to the left side and

this will by electrostatic induction make the right side of Cg minus and the left side plus. The positive grid voltage thus produced will tend to increase the plate current through the choke still more. As a matter of fact, the inductance of the plate choke is so great that the plate current is practically constant and the changes in plate current are supplied by the charging current of the condensers. The grid leak R is in series with a small choke coil. C1 is a blocking

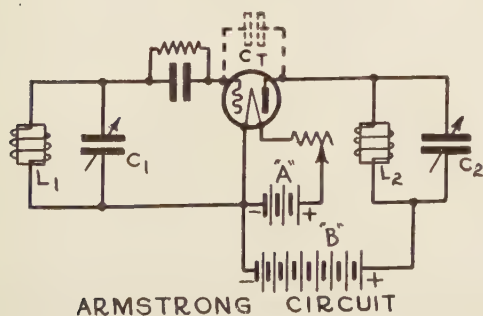


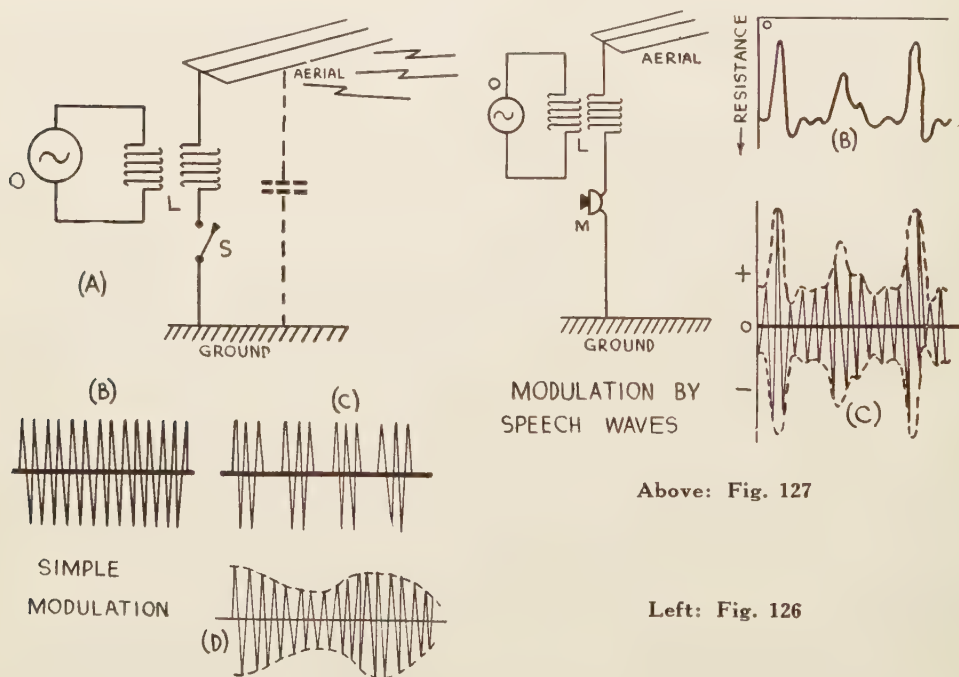
Fig. 125

condenser to prevent the high plate voltage from going through L to the grid. This circuit permits of many modifications for practical use.

182. **ARMSTRONG CIRCUIT:** The Armstrong oscillator is merely a tuned plate, tuned grid regenerative circuit, as shown in Fig. 125, in which feed-back takes place through the plate-grid capacity C_t of the tube, when both circuits are tuned to the same frequency. The action was explained in Article 116.

193. **MODULATION:** Now that we have studied how the vacuum tube can be made to act as a generator of steady high frequency currents, we are in a position to understand how modulation of the high frequency current can be accomplished for practical broadcasting purposes. The purpose and subject of modulation were explained in Chapter 3 and the reader should now review this in order to refresh his memory. Figure 16 should be studied carefully.

184. **EXPLANATION OF MODULATION:** The principle of modulation can perhaps be made clear by the following explanation. First consider an oscillator "O" in Fig. 126A feeding its steady high frequency output current (Fig. 126B) into the primary of coupling coil L . The secondary of this coil is coupled to an antenna and ground system as shown. A switch S is included in the antenna circuit for opening and closing the circuit at will. Now if the oscillator is set



into operation and the switch is rapidly opened and closed, the radiation from the antenna will be in interrupted pulsations (for practical purposes of this discussion), as shown in Fig. 126C.

Now suppose the switch S is replaced by a variable resistance and this resistance is varied in a haphazard manner. This will vary the high frequency current

in the antenna circuit and a picture of the resulting current would look somewhat like Fig. 126D. Notice that the individual cycles of the R. F. current vary in strength, depending upon the amount of resistance inserted in the circuit.

Now suppose the resistance is replaced by a microphone M as shown in Fig. 127. If a person speaks into this microphone the sound waves vibrate the diaphragm and so change the resistance of the microphone in accordance with Fig. 127B. These resistance variations vary the individual cycles of the high frequency current somewhat as shown in Fig. 127C. Notice that the high frequency carrier current furnished by the oscillator has been modulated in accordance with the speech waves which actuate the microphone. When the resistance of the microphone is low, the current is high and vice versa.

Modulation can be accomplished in either of the three main ways: first, by using suitable apparatus the output or continuous wave of an oscillator can be changed or modulated directly by speech; second, by varying the grid voltage of the oscillator by speech wave fluctuations; third, by controlling the direct current supplied to the oscillator tube or tubes.

185. **POWER OUTPUT ABSORPTION MODULATOR:** The circuit of Fig. 127 is impractical when any considerable amount of power is to be modu-

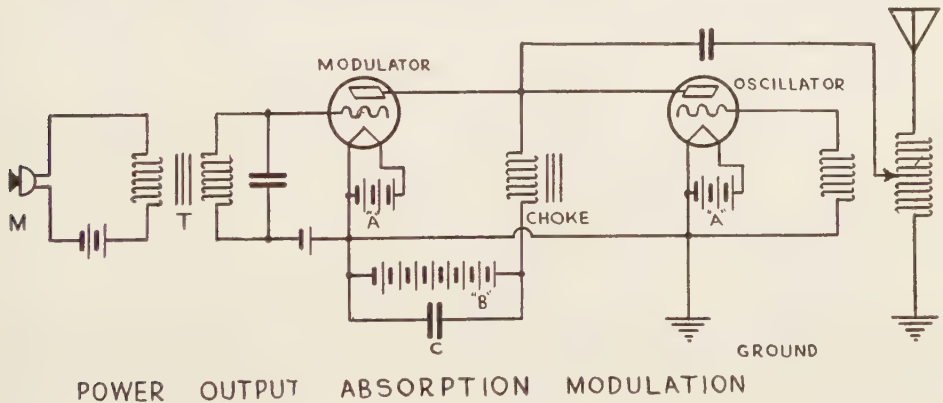


Fig. 128

lated, as the power handling capacity of a microphone is very small. In practice vacuum tubes are used for modulation.

Fig. 128 shows the connections for the oscillator and modulator tubes in the popular power output absorption method. The microphone M is coupled to the grid circuit of the modulator tube by the modulation transformer T. The battery furnishes the steady current for the microphone circuit. The modulator tube is arranged to continuously absorb some of the plate power of the oscillator, the amount absorbed varying with the e.m.f. induced in the grid circuit of the modulator by the current variations in the microphone circuit.

As the grid potential of the modulator tube is varied by the microphone, its plate impedance varies, and this in turn varies the amount of current returned from the plate circuit of the oscillator tube to the filament, through the modulator

tube. There is another return path for the current through the antenna inductance. If the former current increases the current through the antenna coil must proportionately decrease, and since the radiated waves from the antenna depend on the antenna current, the output of the oscillator is modulated in accordance with the wave form of the speech wave which actuates the microphone. Obviously, the operation of this modulator system depends on the curvature of the grid voltage-plate current characteristic of the tube.

186. **GRID MODULATOR:** The grid modulation system is used extensively. Fig. 129 shows a simple form of this circuit. The oscillator tube and the microphone input circuit are both coupled to the grid circuit of the modulator tube.

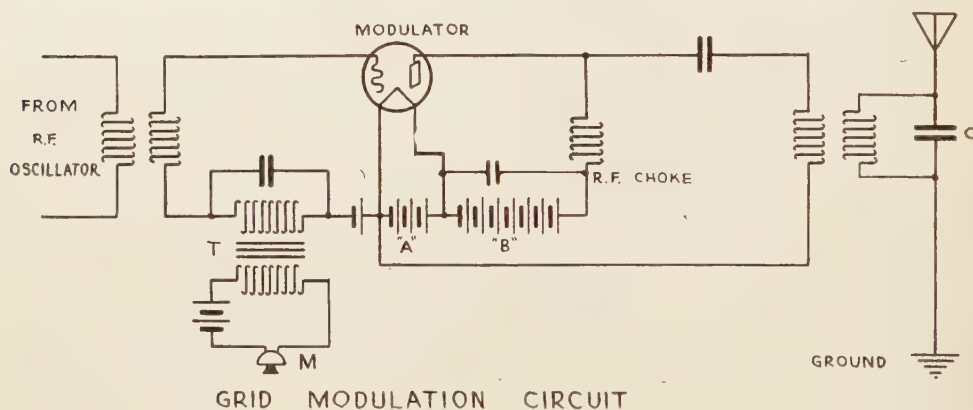


Fig. 129

The plate voltage and grid bias on this tube are adjusted so the tube operates on the lower bend of its characteristic curve. The resultant grid potential at each instant is the sum of the instantaneous values of the radio frequency e.m.f. and the audio frequency e.m.f. induced in the grid circuit. The amplitude of the resulting radio frequency current in the plate circuit varies in accordance with the audio frequency wave form. This current flow through the primary of antenna coil, whose secondary is tuned by the combined capacity of condenser C and the capacity of the aerial. The induced currents in the secondary produce the radiation from the antenna.

Another simplified method of grid modulation used in very small transmitters is to induce the audio frequency speech wave e.m.f. directly into the grid circuit of a vacuum tube oscillator, as shown in Fig. 130. The theoretical operating principles of this circuit are the same as for the previous circuit.

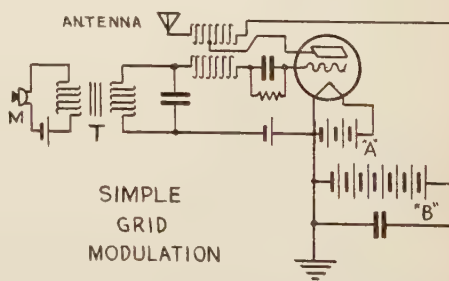
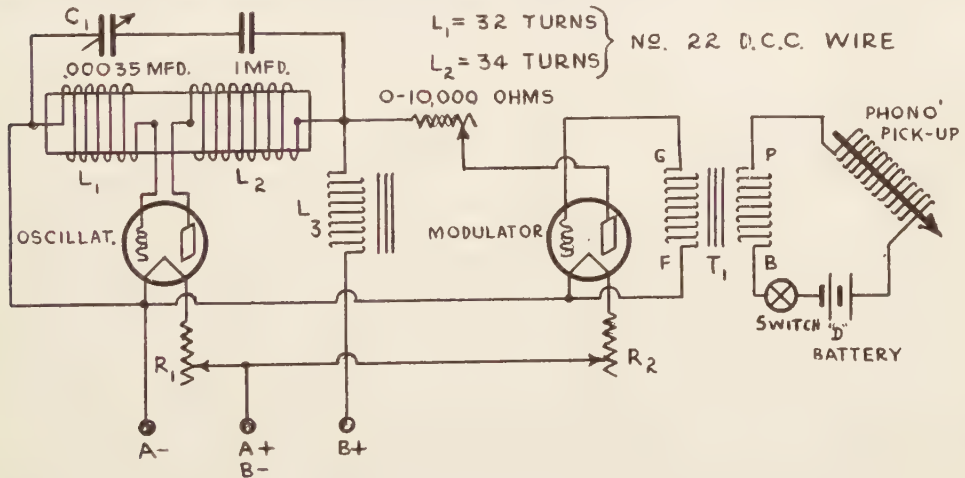


Fig. 130

The modulation circuits discussed above are only a few of the very large number of systems in practical use, but they are typical of such systems, and if the reader understands these he will have no difficulty in grasping any other system. The main point to remember is that every such system must have some means of changing the amplitude of the antenna current in accordance with sound waves.

187. **MODULATED R. F. OSCILLATOR FOR TESTS:** Fig. 131 shows the circuit for a simple modulated R. F. oscillator or miniature broadcasting station which can easily be built by any experimenter. It can be used for a



MODULATED R.F. OSCILLATOR FOR TEST WORK

Fig. 131

variety of purposes, such as tests on receivers, as a source of pure R. F. current or modulated R. F. current for experiments and measurements, for balancing gang tuning condensers, testing for over-all amplification, etc. It will produce a strong carrier wave on any desired wavelength in the broadcast band.

Coils L1 and L2 are wound on a single 3" diameter form with No. 22 D. C. C. wire. L1 consists of 32 turns and L2 contains 34 turns. Both coils are wound in the same direction, and next to each other. Tuning condenser C1 is of .00035 mfd. capacity and should be well constructed to prevent shorted plates. The audio choke L3 may, on account of the small plate current, be the secondary of an audio transformer whose primary is burnt out. The two tubes can be either of the 199 type (with 30 ohms each for R1 and R2) or can be UX-201A tubes (with 15 ohms each for R1 and R2). Three No. 6 dry cells connected in series will do for the "A" battery if 199 tubes are used. A six volt storage "A" battery should be used if 201A tubes are employed. Either a standard modulation transformer or a good low ratio audio transformer is need for T1. Either a phonograph pickup unit or a microphone can be used to obtain a source of tone to modulate the oscillator. If a microphone is used, battery D of from 6 to 12 volts

is necessary. If the phono pickup is used the battery should be removed from the circuit. A switch "S" is inserted to open the circuit when the microphone is not in use, so as to lengthen the life of the battery.

From 60 to 90 volts will be required for the "B" supply. The 0 to 10,000 ohm variable resistance in the plate circuit of the modulator tube is used to adjust the plate voltage to the best operating value for undistorted transmission.

To test the unit for oscillation, take a broadcast receiver and tune it to any station near the middle of the dial. Light up the tubes in the oscillator unit and place it near the broadcast receiver. Tune C1 slowly from its minimum to its maximum setting. As the unit passes through the frequency band that the receiver is operating on, a loud squeal will result provided that the oscillator tube is oscillating. If the squeal does not develop, simply reverse the connections to coil L2. Now test again for the squeal.

If the unit is to be used as a straight R. F. oscillator, simply disconnect the pick-up unit or microphone or else turn out the filament of the oscillator tube by means of R2.

The oscillator unit can be calibrated by following the calibration instructions given for the portable R. F. oscillator in article 179. The modulator tube should not be used while calibrating the unit.

188. **BROADCASTING STATION:** The circuit diagram for a complete

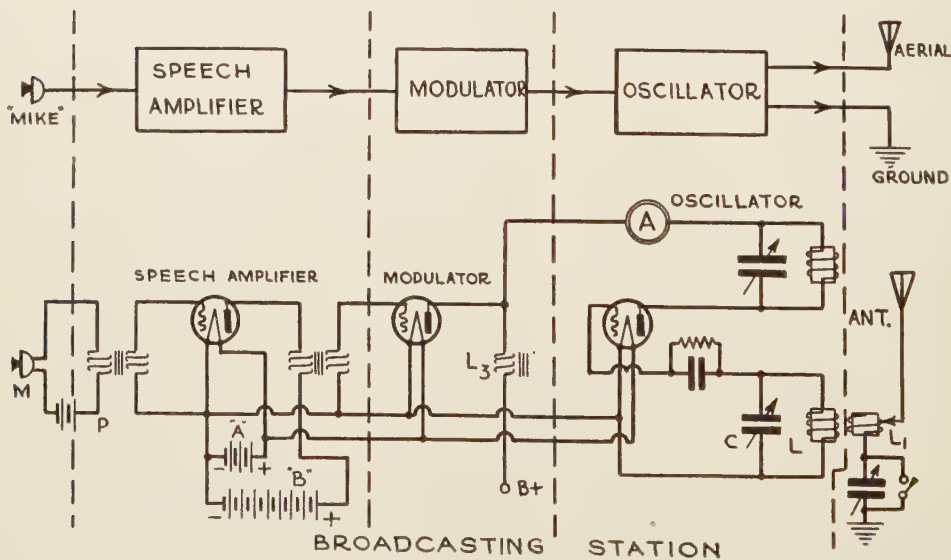


Fig. 132

simple broadcasting station is given in Fig. 132. The system, in its simplest form, consists of a microphone and a speech amplifier which amplifies the small current changes (usually consists of three or four stages of amplification) which the

microphone sets up in the primary P. The amplified impulses are applied to the grid of the modulator tube. The Heising system of modulation employs the modulator tube to vary the plate power supplied to the oscillator tube. This is done through the plate choke L3. Hence the high frequency current generated by the oscillator is varied in amplitude to conform with the variations in plate power produced by the modulator (Figs. 16C and 16D), and these variations correspond exactly with the voice variations at the microphone. Thus the current transferred to the aerial circuit is a high frequency current (frequency determined by L and C), whose amplitude varies in accordance with the voice variations. Inductance L1, combined with the capacity of the aerial, tunes the aerial to the carrier frequency, for maximum current in the aerial circuit.

189. **AUDIO OSCILLATOR:** The production of audio frequency oscillations can be accomplished in much the same way as for R. F. oscillations. The circuit for a simple audio oscillator suitable for the generation of audio frequency currents which can be varied from about 30 cycles to above audibility is shown in Fig. 133. It is particularly useful in testing frequency response of loud

speakers, audio systems, etc. The tube can be either a 201A or 112A. The latter is preferable, as it has a greater output and will not overload as easily as the 201A. The transformer T is a high grade audio transformer, of about 3 to 1 ratio. The primary is in the plate circuit and the secondary is in the grid circuit. Variation in frequency is obtained by manipulating the variable grid resistance; the lower this resistance, the lower the frequency of the plate current output. If the tube refuses to oscillate, the connections of either the primary or the secondary of

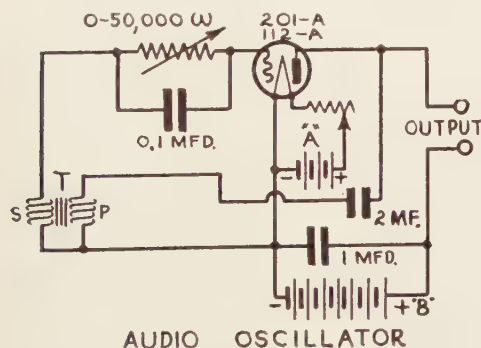


Fig. 133

the audio transformer should be reversed, or another tried.

190. **SUPER-HETERODYNE RECEIVER:** Because of the many difficulties encountered in the construction of R. F. amplifiers of high amplification, due to oscillation feedback, etc., Armstrong devised a method of amplification called the super-heterodyne. In this circuit no attempt is made to amplify the incoming currents at their high frequencies. Instead, they are changed to similar currents of much lower frequency which can easily be amplified efficiently by means of fixed interstage transformers. After being amplified by this low frequency intermediate amplifier, they are rectified in the usual way by a detector tube and passed through the audio frequency amplifier. The transformation of the original wavelength to the higher wavelength (lower frequency) is accomplished by means of the beat or heterodyne principle. In practice a local oscillator tube is so adjusted as to emit a wavelength which can be controlled by means of a variable condenser. This wave is so adjusted that it will fall either slightly above or slightly below the frequency of the incoming wave, so that an overlap

or beat note is created by the two frequencies which corresponds to the wavelength to which each stage of the intermediate amplifier is permanently and sharply tuned to resonance. Fig. 134 shows a simple outline diagram of the system. The first tube is commonly called the first detector, although this is a misnomer, for the function of this tube is not one of detection. Rather, it is a mixing or frequency changing tube for it is here that the frequency of the incoming wave is changed or mixed with that of the oscillator, producing the beat or intermediate frequency.

191. FREQUENCY CHANGING:

Fig. 135 shows the operation of the frequency changer. A vacuum tube T is connected as a detector and has a tuned grid circuit L_1, C_1 , and a tuned plate circuit L_2, C_2 . Circuit "O", which has a steady high frequency current flowing in it, is coupled to the grid circuit by the coils. Let us assume that circuit L_1, C_1 is tuned to an incoming signal "A" (Fig. 136) at 200 meters (1,500 kilocycles), and that circuit "O" is connected to an oscillator adjusted to have a frequency of 1,470 kilocycles, shown by "B" (Fig. 136).

We then have a combination of two frequencies impressed across the grid circuit of tube T. These two frequencies combine to produce a resulting wave Fig. 136C, which has a frequency equal to the difference of these two, or 30 kilocycles. (This wave is obtained by superimposing curve A or curve B and then adding them together, that is, for each point on one of the waves, the vertical

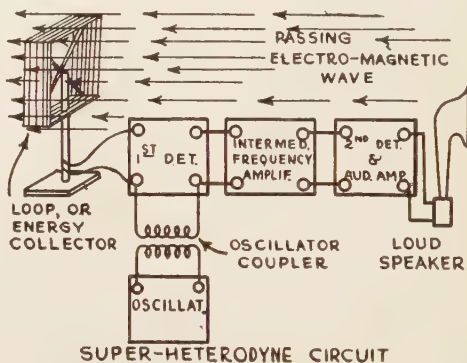
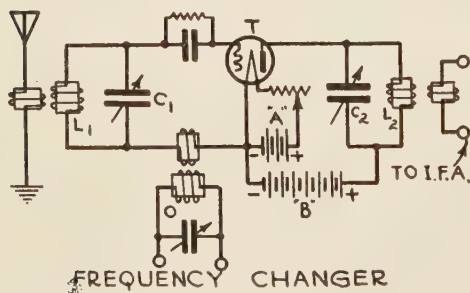


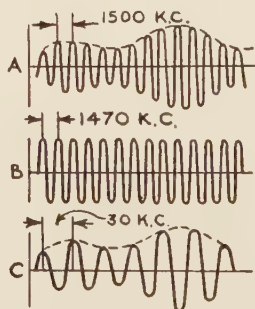
Fig. 134



Above: Fig. 135

Right: Fig. 136

HETERODYNING OF TWO CURRENTS



distance on the other is added to it algebraically giving the resultant wave C.) Since the vertical heights are simply added, it is evident that any kinks (such as those due to modulation) in either of the curves give similar kinks in the resultant curve. This difference frequency which will be present in the plate circuit of tube T is called the intermediate frequency and is always a lower frequency than either of the other two. (There is also a higher frequency equal to the sum of the combining frequencies but this is not used in the usual super-heterodyne.)

in an oscillating condition and its tuned circuits must be detuned from the incoming frequency to an amount determined by the desired intermediate frequency.

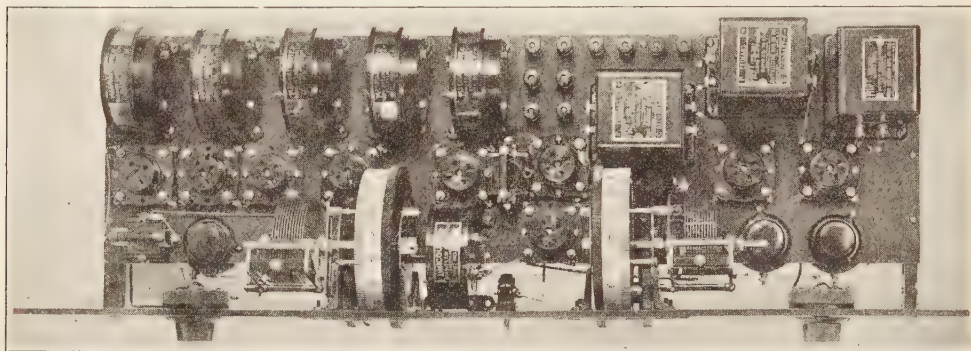


Fig. 138. Nine Tube Super-Heterodyne Receiver of Fig. 137. The Intermediate Frequency Transformers Are Shown at the Upper Left

Some super-heterodyne sets employ a stage of tuned R. F. amplification ahead of the first detector for increased sensitivity. Still others employ regeneration in the loop pickup circuit.

REVIEW QUESTIONS

1. State two uses for vacuum tube oscillators.
2. Explain how a vacuum tube may be made to oscillate. What determines the frequency of the oscillations?
3. Explain the operation of the Hartley oscillator circuit.
4. Explain the operation of the Colpitts circuit.
5. Describe a simple audio oscillator.
6. Describe the principle of frequency changing and the super-heterodyne receiver.
7. What is the cause of the double oscillator setting in a super-heterodyne?
8. Explain what is meant by modulation. State three ways by which modulation can be accomplished.
9. Explain the principle of grid modulation; of plate modulation.
10. How is the principle of modulation used in the broadcasting station?

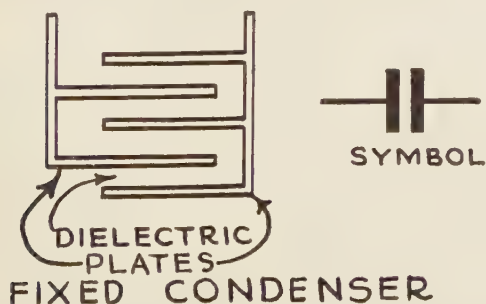
CHAPTER 14.

CONDENSERS AND SINGLE DIAL CONTROL.

CONDENSERS—FIXED CONDENSERS—INDUCTIVE WINDINGS—ELECTROLYTIC CONDENSERS—VARIABLE CONDENSERS—SHAPES OF PLATES—S. L. C.—S. L. W.—S. L. F.—CENTRALINE FREQUENCY—REDUCTION OF TUNING CONTROLS—CONDENSER GANGING—ANTENNA COMPENSATION—EQUALIZING THE CIRCUITS—MATCHING TUNING CIRCUITS.

193. **CONDENSERS:** A condenser consists of two or more metallic plates or wires separated by a non-conducting substance such as air, mica or paper (Fig. 139). Alternating currents can pass through a condenser *circuit* (but not through the condenser itself, see Fig. 14) because they continuously charge and discharge the plates. Direct currents charge the plates only once, when the circuit is closed. Condensers are constructed so their capacities are either fixed or variable. Both fixed and variable condensers of many sizes are used extensively in radio work. The function of a condenser is to store up electricity during the charging period and to release it on discharge.

194. **FIXED CONDENSERS:** The capacity of a condenser is stated in terms of the quantity of electricity it will hold per volt. A condenser which stores a coulomb of electricity when the applied pressure is one volt has a capacity of one farad. A condenser of one farad capacity would be extremely large. Therefore, the microfarad (one-millionth of a farad) has become the popular unit for capacity.



Above: Fig. 140. Small Fixed Mica Condenser in Bakelite Case

Left: Fig. 139

The capacity of a condenser is directly proportional to the total exposed area of the plates, inversely proportional to the distance between the plates and directly proportional to a factor *K*, called the dielectric constant. The factor *K* depends upon the *material* used as a dielectric. It is equal to the ratio of the capacity of a condenser using the particular material as a dielectric, to the capacity of the same

condenser using air as a dielectric. The table below gives the values of K for various materials. This shows that if any material other than air is used as a dielectric the capacity is increased. Therefore, by using mica or some other dielectric in fixed condensers they can be made much more compact for a given capacity, than if air were used.

Material	K
Air	1
Glass	4 to 10
Mica	4 to 8
Hard Rubber	2 to 4
Paraffin	3 to 4
Paper	1.5 to 3
Sulphur	3 to 4.2
Shellac	3 to 3.7
Wood	3 to 5
Bakelite	5 to 7.5
Vaseline	1 to 3
Porcelain	3 to 5
Quartz	4 to 5

The capacity of a condenser can be computed from the general equation

$$C = \frac{2250 A K}{10^{10} D}$$

Where C=capacity of condenser in microfarads.

K= dielectric constant.

A= "total" area of dielectric between plates, in square inches.

D=thickness of dielectric in inches.

The capacity of a condenser can be varied by varying any or all of these factors. The commonest dielectric used in variable condensers is air. Most small fixed condensers (Fig. 140) employ a mica dielectric because of its low losses. The elements are moulded in a Bakelite casing with terminals for connection. These are made in sizes from about 0.00002 mfd., up to 0.015 mfd. Larger condensers of

$\frac{1}{2}$ mfd. capacity and over generally use a high grade pure linen paper dielectric rolled or wound up compactly with metal foil plates. Roughly, the voltage which condensers of this type are able to withstand without breaking down depends upon the thickness of the dielectric as well as the material. Condensers built to withstand 1000 volts are not uncommon in power amplifiers of radio sets. High voltage "paper condensers" usually have three or four sheets of paper between the

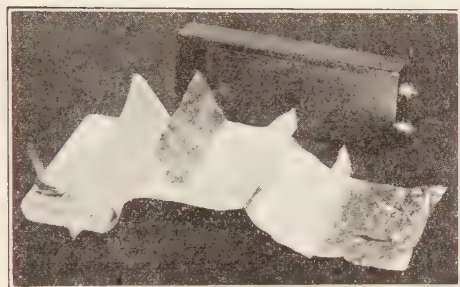
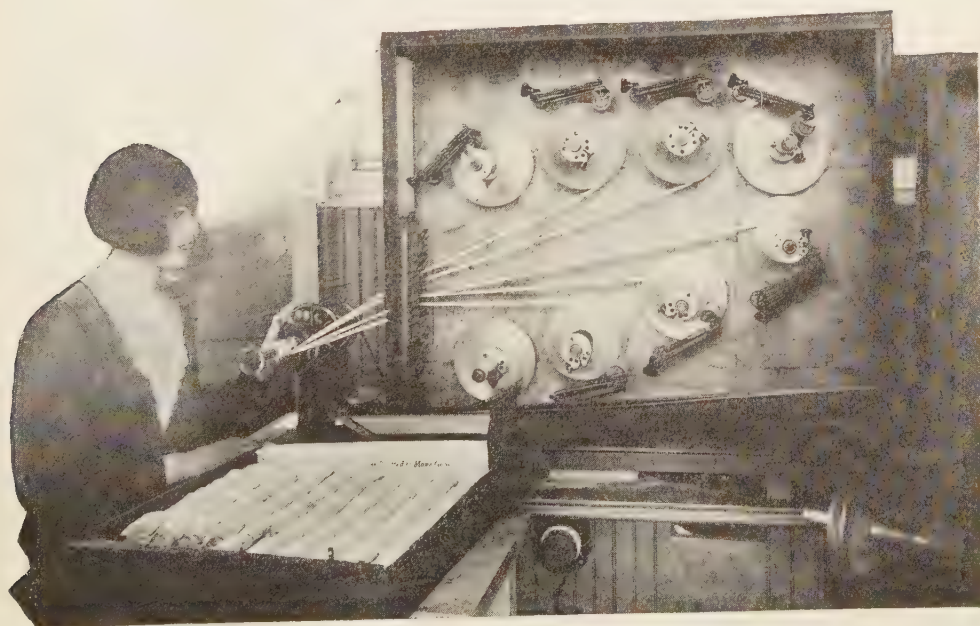


Fig. 141—Fixed Condenser Opened to Show-Metal Foil Plates and Paper Dielectric. Condenser Sealed in Metal Case

plates instead of one thicker sheet. One reason for this is that there is very little likelihood of any little microscopic pin holes occurring in all three papers at the same place and thus causing breakdown. Just one pinhole would be enough to break down a single paper condenser. Fixed condensers are thoroughly dried in a large vacuum drying oven and then impregnated under pressure with a wax sealing compound to keep out dirt and moisture. They are usually sealed in metal cans, with connecting terminals protruding (see Fig. 141).



Photos Courtesy Pilot Radio & Tube Corp.

Fig. 141A—Side View of a Condenser Winding Machine. Notice How the Sheets of Paper and Metal Foil Feed Thru the End of the Dust-Proof Case onto the Winding Spindle

195. **INDUCTIVE WINDINGS:** Paper condensers can be wound up so they are inductive or non-inductive. In the first type, the foil used is narrower than the paper, and contact is made with the foil plates by a copper or other metal strip inserted into the winding at the end, as shown in Fig. 142. The strips make contact at only one point with the foil plates, which may be as much as 30 to 50 or more feet long depending on the capacity. Obviously such a condenser has capacitance but having a large number of turns it also has inductance, which is objectionable at high radio frequencies.

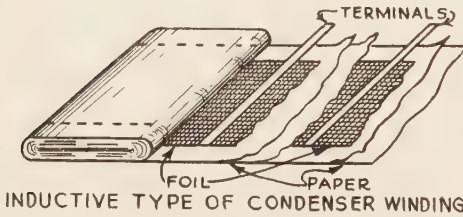


Fig. 142

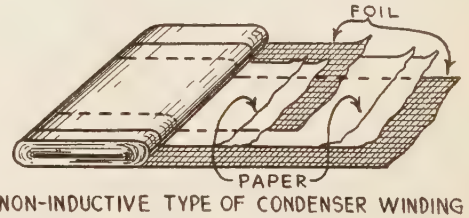


Fig. 143

The non-inductive type is wound with foil which is usually almost the same width as the paper. The winding is staggered (Fig. 143), so that foil is visible from each end. The terminals are metal strips soldered to the foil extending across each end. Flexible leads are soldered to these strips. As the terminals make contact with every turn of the foil, the condenser is non-inductive. Also, the D. C. resistance of each plate of the condenser is cut down practically to zero by this construction, since the length of the current path is very small and the area is very large. Fig. 143A shows several filter condensers of the wound type before and after being sealed into the metal cans for commercial use.

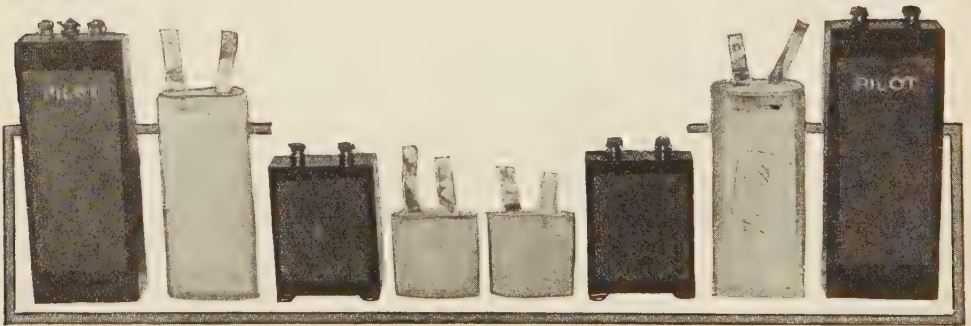
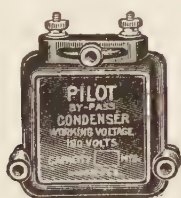


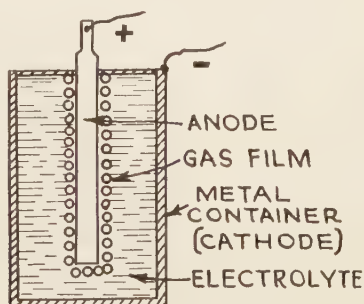
Fig. 143A—A Group of Fixed Condensers, Showing the Wound Units Before Being Sealed, and the Completed Condensers in Metal Cases

196. **ELECTROLYTIC CONDENSERS:** An electrolytic condenser usually consists of one or more metal plates immersed in a suitable solution to which electrical contact is made by another metal plate. This latter plate may actually be a

metal container for the solution itself, as in Fig. 144. The first plate, called the anode, is usually of aluminum and the solution can be one of borax. One generally accepted theory as to the action which takes place is that the solution acting chemically on the aluminum plate produces an infinitely thin gas layer all around the plate when it is "formed." This gas layer of great thinness is all that separates the conductive aluminum from the conductive liquid, i.e., it is the dielectric. Thus we have two conductors of considerable area (the aluminum plate is usually corrugated to greatly increase its surface) separated by a dielectric of great thinness. Hence it is possible to get enormously large capacities in condensers of small physical size. One commercial type in a three-inch diameter can have a capacity of 80 mfd. The breakdown voltage is quite low, but several condensers can be connected in series on high voltage circuits. If the oxide layer is punctured by excessive voltage, current is momentarily passed through the condenser and the film is immediately built up again without permanent damage to the apparatus. The aluminum must always be connected to the positive terminal, or the condenser will be ruined. Large capacity condensers of this type are especially advantageous in "B" eliminators. They can be used on pulsating or smooth direct current but cannot be used on alternating current on account of the polarity reversal.



Above: Fig. 142A—0.5 Mfd. Fixed Condenser in Bakelite Case.



Right: Fig. 144—Electrolytic Condenser

ELECTROLYTIC CONDENSER

197. VARIABLE CONDENSERS: Variable condensers which are used extensively for tuning radio frequency circuits consist of a group of stationary plates (stator) arranged so that a set of rotating plates (rotor) can be moved in and out between them without touching. The dielectric (the space between them) is air. When the plates are all meshed (Fig. 145A) the full areas of the plates are exposed to each other and the maximum capacity exists; when they are all out of mesh (Fig. 145B), the minimum capacity exists; and for any position in between these (Fig. 145C), various intermediate capacities exist.

Condensers are usually made with thin brass or aluminum plates supported by a rigid framework of brass or aluminum. The stator plates are held in position and insulated from the frame by insulating strips (see Fig. 150). The stator and rotor plates should not touch, for a short circuit would then result. Rotor bearings should work smoothly and the entire condenser should be rigid.

198. SHAPES OF PLATES: The variation of capacity is caused by chang-

ing the amount of interleaving of the plates and hence the area between them. The rate at which capacity changes as the plates are rotated depends on the shape of the plates. There are four well known shapes at the present time, devised to secure certain tuning characteristics when used with a coil in a tuned circuit.

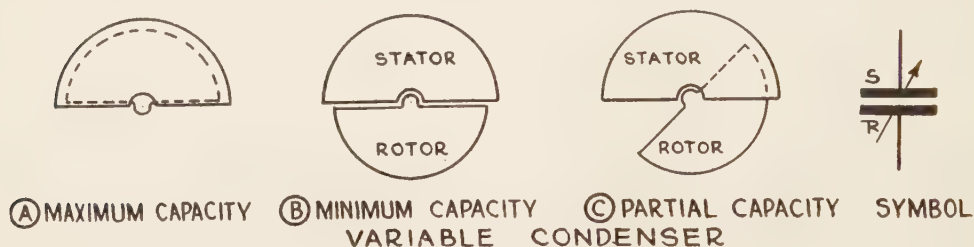


Fig. 145

199. **STRAIGHT LINE CAPACITY:** Fig. 146 shows a condenser with semi-circular rotor and stator plates. In a condenser of this type it is obvious that the capacity is proportional to the angle of rotation of the rotor or settings of the condenser dial. That is, for equal increases of rotation, equal increases of capacity are obtained. If a graph is plotted with dial settings against capacity, it is a straight line. Now if this condenser is connected to the fixed tuning coil L in the usual way, as the condenser is varied the circuit is tuned to various frequencies. The variation of the resonant frequency with condenser dial settings is

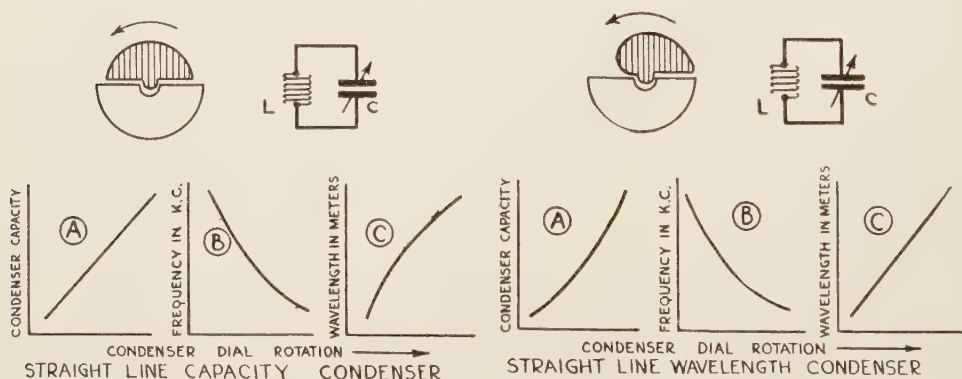


Fig. 146

Fig. 147

shown in Fig. 146B. The curve becomes steeper at the lower end of the scale, showing that a given rotation of the dial near this end produces a much greater change in frequency or wavelength than an equal rotation at the upper end of the scale. Therefore, since broadcasting stations are separated in frequency by 10 kilocycles, it will only take a very small motion of the dial to cover 10 kc. and go from one station to the next, at the lower end of the scale (high frequencies). Hence we find the stations crowded together on the dial at the low wavelengths.

In practice this condition appears still worse because the straight line capacity (S.L.C.) condenser is at a disadvantage when used for tuning circuits of broadcast receivers. It may be useful, however, in laboratory work where equal increases of capacity are desired.

200. **STRAIGHT LINE WAVELENGTH:** An attempt to reduce this crowding of stations at the lower portion of the S. L. C. condenser dial was made by shaping the plates of the condenser so that the variation of the dial is proportional to the *wavelength* of the tuned circuit. This is the straight line wavelength type (S. L. W.), and the condenser plates and curves are shown in Fig. 147. Since the wavelength curve is a straight line, a given change in dial setting anywhere produces the same change in wavelength. But the broadcasting stations are not separated equally in wavelengths, so that actually with this type of condenser the low wavelength stations are still crowded at the lower end of the dial, although there is a decided improvement over the S. L. C. type. The stations at the upper wavelengths are also crowded. However, the separation of the stations

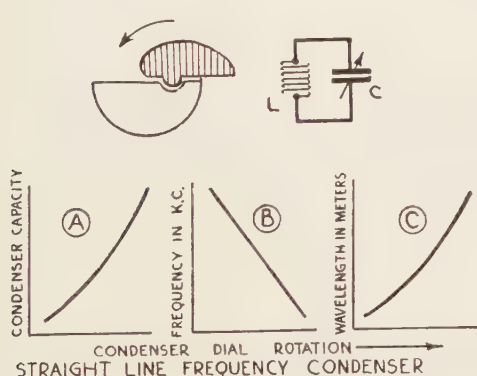


Fig. 148

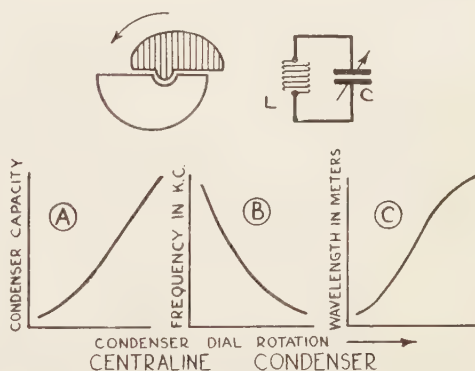


Fig. 149

around the middle of the dial is practically perfect. This type of condenser is useful in wavemeters or oscillators where it is desired to have the dial reading proportional to the wavelength.

201. **STRAIGHT LINE FREQUENCY:** The straight line frequency condenser (S. L. F.), is designed with a plate shape which makes the rotation of the dial proportional to the *frequency* of the tuned circuit. With this type of condenser (Fig. 148) stations separated by 10 kilocycles in frequency come in at equally separated points on the dial. The trouble is that the high power broadcasting stations are distributed, in general, over the upper end of the scale. Hence it is of great importance that the latter be separated properly. The S. L. F. condenser does not do this, but rather crowds these stations at the upper wavelengths, and also at the middle band under the present station separations and locations. This type of condenser is useful in oscillators where it is desired to have the dial reading proportional to the frequency.

202. **CENTRALINE FREQUENCY:** Condensers such as the "centraline" (Fig. 149) "midline," etc., were designed to eliminate all these disadvantages by

employing a plate shape which gives a composite tuning curve, that is, gives approximately S. L. F. tuning at the low end of the dial, S. L. W. tuning at the center region, and S. L. C. tuning at the upper wavelengths. Study the curves in Fig. 149.

These desirable tuning characteristics can be secured by irregular shaping of either the rotor plates, stator plates, or both. The physical dimensions of the condenser should be kept small, so that not much space will be required when installed in a receiver.

It is evident that the *effect* of the S. L. W., S. L. F., and Centraline condensers is strictly a slow motion action, having a variable reduction and gradually changing as the condenser is advanced. The same result can be accomplished by a slow motion vernier dial constructed to automatically vary its reduction ratio to give the effect of any of these shaped plates when used with an S. L. C. condenser.



Fig. 150—Four Tuning Condensers Designed to Produce Various Tuning Characteristics

The photograph of Fig. 150 shows one of each of the types of condensers mentioned, showing the shapes of the plates.

Condensers are made in various maximum capacities, but the 0.0005 mfd., (usually 23 plates) and the 0.00035 mfd., (usually 17 plates), sizes have become most popular for tuning. Small midget condensers ranging in maximum capacity from about 0.000015 mfd. to 0.0001 mfd. find a variety of uses as verniers for the larger condensers, for neutralizing, etc. Fig. 151 shows a commercial form of midget condenser.

203. REDUCTION OF TUNING CONTROLS: A study of the circuit diagram of a two stage tuned R. F. amplifier and detector (Fig. 152) shows that tuning of the receiver is accomplished by rotating the condenser dials of C1, C2 and C3, three in all. This makes the manipulation awkward. Now the tuned circuit L2-C2 works out of the plate circuit of one tube into the grid circuit of a similar tube. The same thing is true of L3-C3. Therefore, if the coils L2 and L3, the condensers C2 and C3, and all stray inductances and capacities are exactly similar, the two condenser settings will be exactly the same for any station tuned in. Therefore, these condensers can be ganged together and operated by a single

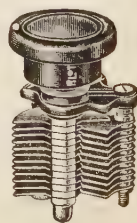


Fig. 151—Midget Condenser

control. The tuned circuit L_1-C_1 , however, is coupled to the antenna, and unless the coupling between L_A and L_1 is extremely loose, the antenna inductance and capacity will affect the tuned circuit so that condenser C_1 will not tune in

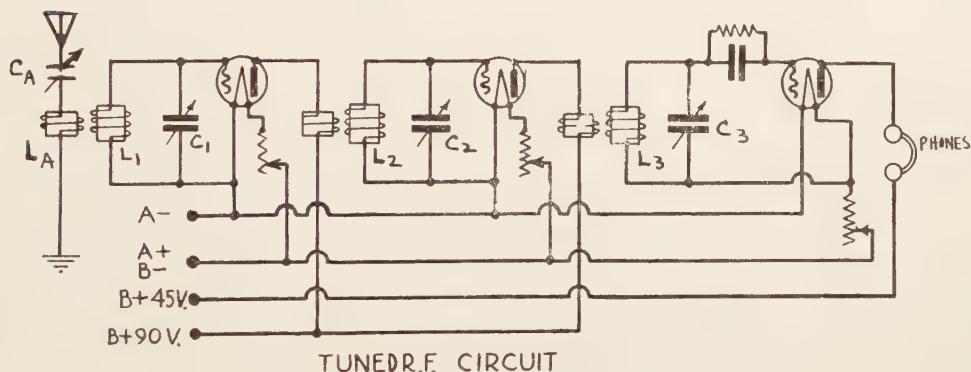


Fig. 152

exact step with the other two condensers and therefore cannot be successfully ganged to them with this arrangement.

204. **CONDENSER GANGING:** There are several ways of ganging condensers C_2 and C_3 together. One way is to have them constructed with one frame and a common rotor shaft, so that the rotor shaft turns both sets of plates simultaneously. A three gang condenser of this type is shown in the photograph of Fig. 153. As the rotors are all electrically connected, it is evident that the grid returns of the amplifier tubes must go either to the minus side of the filament or to the negative terminal of a $1\frac{1}{2}$ to 3-volt "C" battery. The detector circuit grid return can be brought to the negative side of the filament, however, if the grid leak is connected as shown in Fig. 154. (See chapter on detection). This accomplishes the desired result.

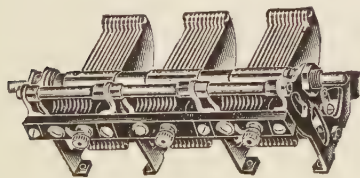


Fig. 153—Three Gang Condenser

Another mechanical expedient used in many sets is to couple two or more individual condensers together by means of a belt and pulley arrangement, rack and pinions, flexible couplings, or link motions. This consideration is merely mechanical; the main point is that the condensers are turned simultaneously and the number of tuning controls is reduced.

205. **ANTENNA COMPENSATION:**

The problem of ganging condenser C_1 with the others in order to make a true single control receiver presents more difficulties on account of the effects of the antenna circuit. Sometimes a small midget variable or fixed condenser C_A of from .0001 to .002 mid. capacity is connected in series with the antenna, as shown in Figs. 152 and 154. Since this

capacity is really in series with the capacity of the antenna (see Fig. 25), it aids in reducing the total capacity of the antenna circuit, thus minimizing its effect on the first tuned circuit. As most receiving antennas differ as to length, height, etc.,

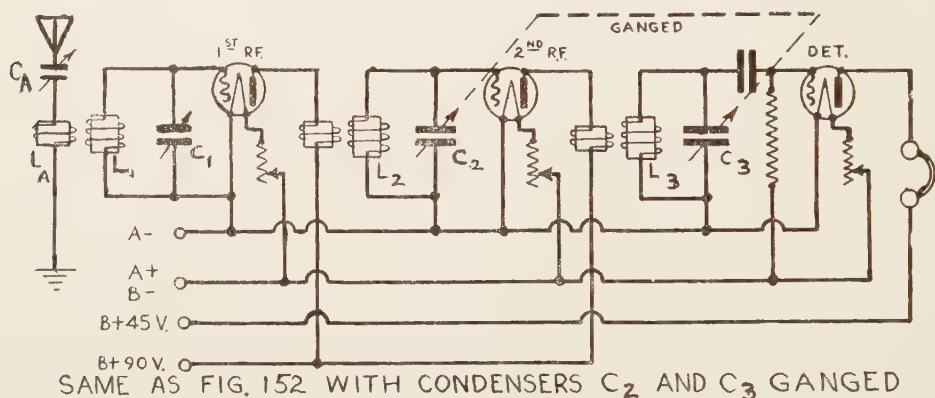


Fig. 154

a variable condenser connected in this position is sometimes practical. One method which permits the ganging of all three condensers is shown in Fig. 155A. Here, tuned circuit L_1LC has been coupled directly to the plate circuit of an additional tube T through a resistance of about 2000 ohms. It is now similar to the other two tuned circuits and the three can all be controlled together. The potential drop across the resistance is applied to the grid of the first tube. This tube does not add any amplification to the circuit, but acts merely as a coupling device. With this arrangement the antenna constants have little or no effect upon the tuning of the following circuit. However, an untuned antenna stage often produces harmonics and "cross modulation" due to rectification being set up in the first R.F. tube by strong local signals. The audio currents produced in its plate circuit modulate the incoming R.F. signals of all other stations, and thus the local program appears as a modulation on all other stations received. The remedy for these undesirable effects is either to use a band-pass filter or pre-selector system, or to employ very loose coupling between the primary L_A and secondary L_1 of

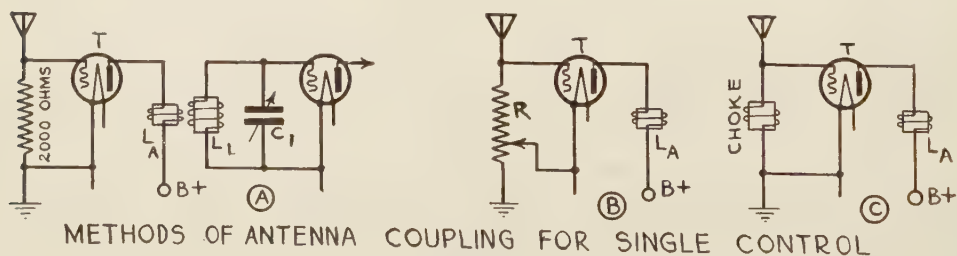


Fig. 155

a tuned antenna coil as shown in Fig. 154. The resulting loss of sensitivity can be compensated for by increasing the R.F. amplification. This is easy when

screen-grid tubes are used. Untuned antenna schemes are becoming unpopular on account of these objectionable factors.

If a variable resistance R is used as at Fig. 155B, it can also be used as a volume control by varying the number of turns included in the grid circuit.

Fig. 155C shows another method where a non-resonant choke coil is used to produce a potential difference between grid and filament.

In some cases it has been possible to secure a small voltage step-up in the coupling tube T by utilizing a choke coil connected between the antenna and ground which, in conjunction with the average antenna (capacity about 200 mmfd.) tunes to approximately 200 or 300 meters, and provides a voltage step-up in the neighborhood of four at resonance and diminishing to about one for the remote frequencies. "Cross-modulation" is usually experienced, however.

206. **EQUALIZING THE CIRCUITS:** Gang tuned circuits must be carefully constructed if they are to keep in step with each other over the entire tuning range. It is now possible to buy reliable makes of condensers which are accurately

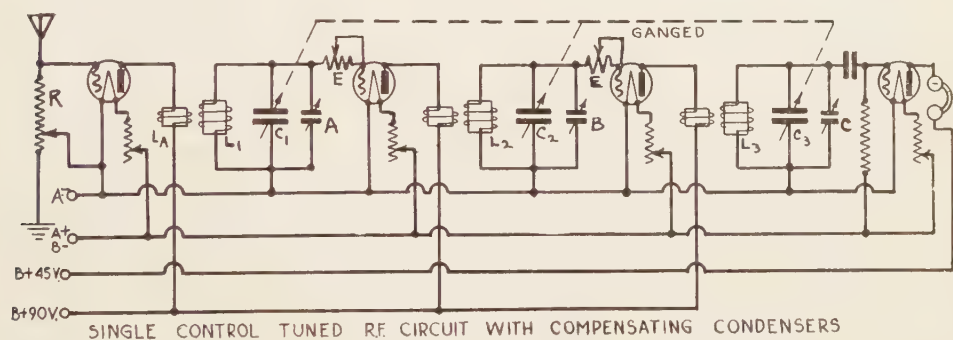


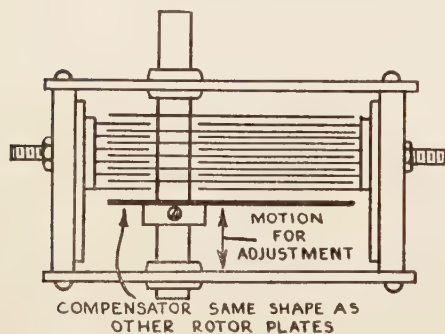
Fig. 156

made so as to be as nearly similar in capacity calibration as is necessary in practical receiving sets.

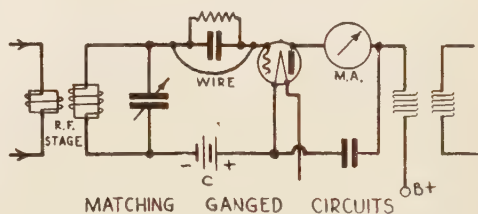
The winding of a number of electrically similar coils is not such an easy task in quantity production. Also, the various stray capacities entering the tuned circuit, such as that between wiring, the grid-filament capacity of the tube, etc., make equalizing of the circuits difficult. Many receivers are equipped with some compensating device which permits exact tuning of each circuit to resonance. In some cases this device consists of a small midget condenser connected in parallel with one of the main tuning units, or one of these condensers on each main tuning unit. Gang condensers are available with these compensating devices already built into them. Fig. 153 shows one of these. The small compensating condensers are at the sides of the main units. Fig. 156 shows the circuit of a single control tuned R. F. amplifier utilizing one of these units. The compensating condensers are indicated by A, B and C. Grid suppressor resistances E are used in the grid circuits of the second and third tubes to suppress possible oscillation.

Another alternative is to design the R. F. transformers so that the individual stages are made just broad enough so that slight discrepancies in tuning are not noticeable.

If semi-circular (S. L. C.) condensers are used for tuning, the adjustment for bringing various stages into step can be made by providing adjustable couplings between the individual rotor units, and slightly advancing one or more of these rotor units, or by adding compensating condensers in parallel with the tuning condensers. If this is done with condensers having other plate shapes (as S. L. W., S. L. F., and Centraline), the capacities become unbalanced as the control dial is advanced. This is due to the fact that the capacity variation per dial division increases as the condenser is turned toward maximum capacity, and the unit which was advanced gains capacity more rapidly than the others. This can be partly avoided by keeping all the rotor plates exactly in step and making up for any inequalities by means of compensating condensers which can be set and left fixed, thus adding a *constant* capacity to the circuit. With this method the stages



CENTRALINE CONDENSER WITH COMPENSATOR



Above: Fig. 158

Left: Fig. 157

will be in step over the center region and slightly out of step at the higher and lower wavelengths. Such circuits can be compensated exactly by having one of the end rotor plates of each gang (as in Fig. 157), adjustable so the distance from it to the other plates can be varied, thus varying the total capacity of the condenser in a way which automatically changes and compensates the correct amount over the whole tuning range. When the correct position of this adjustable plate is found it can be fastened permanently by set screws.

207. MATCHING TUNING CIRCUITS: In order to obtain the best results from a receiver which employs ganged tuning circuits, it is necessary that the set be carefully and thoroughly balanced; otherwise it will tune broadly and will not bring in the many distant stations it would bring in if it were properly adjusted. The balancing operation requires a little patience, but is not difficult.

A practical way of matching circuits in a completed single control receiver consists in connecting a 0 to 5 milliamperes (or smaller) milliammeter in the plate circuit of the detector tube as shown in Fig. 158. For best results the grid leak and condenser should be short circuited with a piece of wire, and a "C" bias of a few volts placed temporarily on the tube. When a station is tuned in on the set, the meter shows a reading depending on the strength of the signal and the amplification of the set. As the meter is sensitive to small current changes in signal input, an adjustment of the compensating condensers produces a change

in scale reading. All compensators should be adjusted for greatest scale reading for perfect matching. This should be checked on several wavelengths. The modu-

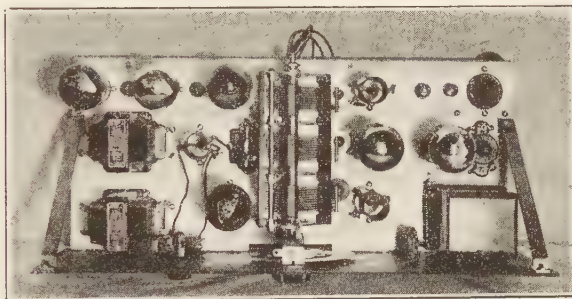


Photo Courtesy Pilot Radio & Tube Corp.

Fig. 159—Single Dial Control 6 Tube T.R.F. Receiver

lated oscillator described in Article 187 of Chapter 13 can be used as a source of signal voltage if desired.

If the grid leak and condenser method is employed, the milliammeter reading will be *reduced* by the carrier current, the greatest *reduction* occurring when all the tuned circuits are at perfect resonance.

A commercial single dial control T. R. F. receiver is shown in the photograph of Fig. 159. The three-gang tuning condenser and layout of parts are clearly shown.

REVIEW QUESTIONS

1. What is a condenser, fixed condenser, variable condenser?
2. What factors does the capacity of a condenser depend upon? What is the dielectric?
3. Explain how a wound type of condenser may have inductance. Explain the construction of a non-inductive wound type of condenser.
4. Why do filter condensers have more than one thickness of paper insulation?
5. Explain the principle of operation and construction of an electrolytic condenser. Why do electrolytic condensers of small physical size have such high capacities? How can electrolytic condensers be connected for use on high voltage circuits?
6. What is a S. L. C., S. L. W., S. L. F., Centraline frequency condenser?
7. How is single control obtained in receivers employing a number of tuned stages of R. F. amplification?
8. What is a gang condenser? What is a compensating condenser?
9. How may the tuned circuits in a single control receiver be matched practically?
10. Why must the tuned circuits in a single control receiver be matched exactly?

CHAPTER 15.

AUDIO AMPLIFICATION.

NEED FOR AUDIO AMPLIFICATION—R. F. VS. A. F. AMPLIFICATION—STUDY OF A. F. AMPLIFICATION—GENERAL DESIRABLE FEATURES IN AN A. F. AMPLIFIER—AMPLIFICATION CURVES—SYSTEMS OF AUDIO AMPLIFIER COUPLING METHODS—TRANSFORMER DESIGN AND TRANSFORMER COUPLED A. F. AMPLIFIER—FREQUENCY RESPONSE CURVES—C. BIAS—TUBE DISTORTION—POWER TUBES—OUTPUT FILTER—RESISTANCE COUPLED A. F. AMPLIFIER—MOTORBOATING—IMPEDANCE COUPLED AMPLIFIER—AUTOFORMER—DUAL IMPEDANCE—COMBINATION COUPLINGS—PUSH-PULL—PARALLEL OUTPUT TUBES—PHONOGRAPH AMPLIFIERS AND PICKUPS—ACTION OF THE PICKUP—SCRATCH FILTERS—PHONOGRAPH REPRODUCING OUTFITS.

208. NEED FOR A. F. AMPLIFICATION: Thus far we have studied the action of the detector and the R. F. amplifier in the modern receiving set. The function of the R. F. amplifier is to increase or amplify the amplitude of the weak signal voltages before they reach the detector. The current in the plate circuit of the detector (Figs. 49 and 50) varies at the audio frequencies of the sounds being transmitted. This current is usually too weak to operate a loud-speaker, and can be amplified again before reaching the loud speaker, by means of vacuum tubes connected up suitably as amplifiers. This is known as audio frequency (A. F.) amplification, and the amplifier is called an audio frequency (A. F.) amplifier.

This presents then, three choices of amplification of the incoming signal, (1) the R. F. signal can be amplified before reaching the detector by successive stages of R. F. amplification; (2) it can be amplified after leaving the detector by successive stages of A. F. amplification; (3) it can be amplified both before and after by a combination of the two, as shown in Fig. 75. A consideration of just what advantages and disadvantages can be secured by each of these methods is important at this time, as it will make clear the reasons for building radio receivers as we do, and the reasons for possible future changes. The question of the correct proportions of R. F. and A. F. amplification in a receiver is assuming great importance lately. A study of the advantages and practical limitations of each of these forms of amplification will give a clearer understanding of the receiver.

209. R. F. vs. A. F. AMPLIFICATION: One advantage of R. F. amplification lies in the fact that if the "C" bias method of detection is employed, the output from the detector tube is nearly proportional to the *square* of the input voltage. This is sometimes called the "square law" of detection. Thus the advantage of R. F. amplification is almost self-obvious, for if the input to the detector is amplified say five times by a stage of R. F. amplification, then the resultant signal

as it leaves the detector is 25 times the original. With a stage of A. F. amplification capable of the same amount of amplification the increase would only be 5.

The advantage of R. F. amplification preceding the detector for weak signal voltages is important, and as the number of stages and resulting R. F. amplification is increased this becomes more and more effective because of the squaring effect. Another advantage lies in the fact that a considerable degree of selectivity is obtained by a multiple stage tuned R. F. amplifier, whereas no selective effect is present in A. F. amplifiers, although too much selectivity results in cutting of sidebands, with resulting distortion of the program, as explained in a previous chapter. Selectivity is becoming of paramount importance as the number of broadcasting stations on the air increases daily.

Since the currents after the detector tube are all of low frequency, any noises introduced in the audio amplifier by low "A" or "B" batteries with consequent variation in supply voltage, hum due to incorrectly designed electric power supply units, loose connections, microphonic tubes, non-uniform emission along the length of the filament, etc., will all be audible and amplified greatly by the A. F. amplifier, since these noises are usually within the A. F. range. They are not likely to cause trouble in the R. F. amplifier because the R. F. transformers do not readily transfer such low frequencies from stage to stage. The limit to the amount of R. F. amplification we can employ depends on the definite limit of the voltage handling capacity of the detector. This is greater for the C bias or so-called "power detector" than the grid-leak and condenser detector. If all of the amplification is to be done before the signal reaches the detector, (that is, no audio amplification is to be used at all) it means that the detector must handle the large signal voltage required to properly operate the loud speaker. There are no practical detector tubes available at the present time which are capable of doing this. Also the practical limit of R. F. amplification seems to be about four stages, with ordinary three-electrode tubes. More stages than this present many difficulties due to feedback effects, etc. The use of the four-electrode screen-grid tube, described in a later chapter, will permit the use of more than three stages of R. F. amplification without serious oscillation difficulties. It is especially valuable since a larger amount of amplification can be obtained with less tubes due to its high amplification factor.

The advantage of A. F. amplification lies in the fact that it is relatively easy to build a two-stage (and with care, a three-stage) A. F. amplifier that is perfectly stable and gives good amplification. The amplifier noises mentioned are a disadvantage, especially when more than two stages are used, but the production of better tubes and associated apparatus is reducing this objection. Atmospheric and other static disturbances are mostly of audio frequency, so that the use of an excessive number of A. F. stages results in unbearable amplification of these noises, especially in the summer months, when such disturbances are almost always present. Another factor is the uneven amplification secured in some A. F. amplifiers. Some frequencies are amplified more than others, with resulting distortion in the loud speaker. This latter factor will be discussed later.

A consideration of all of these factors shows that the question of just how much R. F. or A. F., or R. F. and A. F. amplification it is best to employ must necessarily be answered by a compromise between all of the factors involved. When three-

electrode tubes are used, the best compromise seems to be two to four stages of R. F. amplification followed by detector and A. F. amplification equivalent to that produced by a two-stage transformer coupled amplifier. When four-electrode tubes are used it is sometimes possible to strike the best balance with two or three stages of R. F., detector and one or two stages of A. F. amplification, due to the very high amplification factor of this type of tube. In this chapter we will assume the use of three-electrode tubes only. The four-electrode tube will be considered in a later chapter.

210. GENERAL STUDY OF A. F. AMPLIFICATION: The A. F. amplifier has been the subject of so much controversy that a thorough study of the actual factors and requirements involved in it will be given for the purpose of promoting a common-sense attitude in considerations involving design, parts, etc., used in it. Since the loud speaker is necessarily a governing factor in the reproduction of the audio frequency sounds, its characteristics and effects will be considered with the amplifier, although a discussion of its construction and the forms it can take will be reserved for later consideration.

Once again, due to several limiting factors, the problems of A. F. amplification are best solved by compromising between various undesirable and desirable characteristics in both the transmitting and receiving stations, always keeping in mind the fact that the prime object of the radio receiving apparatus taken as a unit is *to reproduce faithfully, without noticeable change or distortion of any kind, the music or speech produced by the performers in the studio of the broadcasting station.* This should be kept constantly in mind. Notice that “noticeable change” was mentioned, because due to certain characteristics of the human ear, it is possible to have some changes take place without being noticed or detected by the average ear; that is, absolute perfection is not necessary.

A general study of the complete broadcasting system, starting at the microphone and continuing to the loud speaker, is necessary for a complete understanding of the factors involved.

211. FREQUENCY RANGE DESIRED: First, it has been determined by several investigators that the frequency range over which the average human ear can hear is from about 16 to 20,000 cycles per second. The frequency range of human speech is from a little below 100 to about 6,000 cycles per second, the portion most used in conversation lying in the central part of this range. The maximum range of musical sounds with all important harmonics is from about 16 to 10,000 cycles per second (see Fig. 4 in Chapter 1). It has been definitely established experimentally, by progressively eliminating certain frequencies by means of filters, that the frequencies above about 7,000 or 8,000 cycles per second do not add anything to the quality or loudness of the sound, so that they can be eliminated without any noticeable effects. The frequencies below about 32 cycles per second (low “C” on the piano) are seldom played excepting in one instrument—the organ, and very rarely by this. This leaves the range of frequencies which should be reproduced in radio broadcasting between about 32 and 6000 or 7000 cycles per second, the upper limit allowing for reproduction of the second harmonic of the 3000 cycle note, which is above “high C” on the piano and is produced only occasionally by the piccolo and the flute (see Fig. 4, Chapter 1).

212. BROADCASTING STATION FREQUENCY RANGE: It is a

known fact that all of the broadcasting stations do not have the high grade equipment necessary to cover this frequency range, with equal amplification at all frequencies. Many of the larger and well designed stations do, and Fig. 160 shows the frequency transmission curve of Station WEAJ at the time of this writing. Notice the almost flat curve between about 30 and 10,000 cycles, the maximum variation from this flat curve being about 10 per cent, which would not be noticeable by the human ear. In most of the stations with medium grade of equipment, the frequencies below about 200 cycles are poorly amplified.

The frequency range of loud speakers varies greatly. The range of the old type short horn speakers is inadequate for the proper reproduction of all musical frequencies. Many cone speakers do not respond well below about 150 cycles, but give fairly uniform response up to about 8,000 cycles. Horn speakers of the exponential type having an air column of 8 feet or more respond well down to the lower frequencies but fall off at the frequencies above about 6,000 cycles.

It is evident then that the selection of the best general audio frequency ampli-

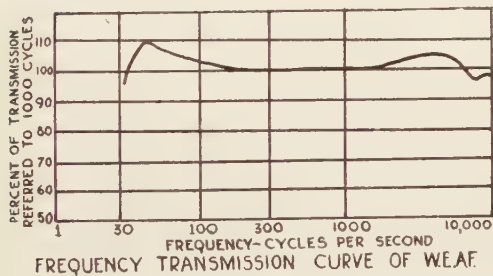


Fig. 160

fier characteristics is a difficult problem, since it depends on several variable factors which are not directly under the control of the designer. It seems, though, that assuming the reception of stations of good quality, and the use of a loud speaker having good frequency response the most desirable frequency characteristics of the audio amplifier are maximum amplification at 32 cycles, falling off gradually toward 8,000 cycles followed by a rapid cut-off of amplifica-

tion at higher frequencies, in order to reduce hissing and other noises due to amplifier instability, heterodyning, static noises, etc. Also the amplification at any one frequency must be constant over the entire range of input voltages at which the amplifier is normally worked.

212. CHARACTERISTICS OF THE EAR: In considering audio systems, some characteristics of the human ear must also be considered. There is a minimum sound intensity below which the human ear cannot detect sounds and a maximum intensity above which sound becomes painful, and these values vary with the frequency. At low levels of sound intensity a change of about 25 per cent is necessary to be detectable. At greater intensities a change of 10 per cent in loudness is detectable by the ear.

At medium frequencies a change in frequency of about 0.3 per cent can be detected, at low frequencies a change of about 1 per cent is necessary for detection by the ear. Another phenomenon of hearing which enters into the sensation of sound is called "masking." Lower pitched tones in a sound deafen the hearer to the higher tones, and this masking effect becomes marked when the loudness of the low tones is great. Masking of the higher notes makes the combined sound appear to be lower in pitch. For true reproduction then, the sounds should be reproduced with about the same loudness as the original sounds in the broadcast

studio. Intense high notes do not appear to mask low notes to any degree.

213. **CUTTING SIDE BANDS:** In this discussion it has been assumed that the audio amplifier is to follow an R. F. amplifier and detector in which no side bands are cut (see Article 157, Chapter 12) and which no other distortion takes place. If this is not the case, the problem becomes further complicated, as the amount of side band suppression is rarely known. If it is known, it can be corrected in the audio frequency amplifier system by increasing amplification of the frequencies which have been suppressed in the R. F. amplifier. This is beyond the scope of the home constructor but is feasible for manufacturers who sell sets complete with built-in loud speakers.

It must be remembered that the cutting off of some of the lower frequencies does not prevent the listener from hearing these notes, for the second (and possible third) harmonics of these are amplified and passed on. The ear partly adds the fundamental pitch of a note, of which only the harmonics are being reproduced, so that these notes are heard although the "quality," "timbre," or "tone color" of the tone is changed. If it were not for this fact some of our older sets and speakers would sound terrible, as they do not reproduce any of the fundamentals below 200 or 300 cycles. Timbre is probably more important in music than in speech, as it is one of the things that distinguishes the tones of the various instruments. In general, the fundamental and first two or three overtones are necessary in order to distinguish clearly the tones of the various instruments.

It can be seen that an A. F. amplifying and reproducing system may fall considerably short of the ideal without giving objectionable reception, due to the peculiarities of hearing of the average person. A trained ear could possibly detect the elimination of frequencies above 8,000 cycles per second from the ordinary run of music, but the average individual would have difficulty in detecting the elimination of frequencies above 6,000 or 7,000 cycles, unless he paid particularly close attention to each of the instruments in an orchestral selection. The factor which guides the design is how good the system will be when apparatus which is not prohibitive in cost is used under practical working conditions.

Now that the requirements of the A. F. amplifier have been studied, the various amplifier systems will be considered in detail. A. F. amplifiers usually consist of two or three stages, each stage comprising a coupling unit and a vacuum tube.

214. **COUPLING METHODS:** In most A. F. amplifiers the greater portion of the amplification is produced by vacuum tubes, and the usual problem of coupling of successive tubes arises. Fig. 161A shows a simplified diagram of a two stage amplifier in which amplification is secured by first stage tube A and output tube B. The coupling units C1 and C2 serve to couple the grid and plate circuits of successive tubes together. The output or varying plate current of one tube must be made to flow through an impedance, producing a varying voltage drop which is applied to the grid circuit of the next tube. This impedance or coupling unit between may take the form of an inductance or a resistance. This leads to three popular main forms of coupling for A. F. amplifiers.

- (1) Transformer Coupling.
- (2) Resistance Coupling.
- (3) Impedance Coupling.

Each system has its own peculiar limitations and advantages. They can all be made to work surprisingly well under certain conditions. The factors governing the choice of any one for particular desired results will now be studied.

215. **TRANSFORMER COUPLED AMPLIFIER:** Fig. 161B shows a circuit diagram of a conventional two-stage transformer coupled amplifier. This is probably the most popular amplifier, since it is possible to obtain a considerable amount of amplification (several hundred) with the use of but two tubes and a comparatively low plate voltage. Transformer coupled A. F. amplifiers form a large majority of the A. F. amplifiers in use in existing receivers. The total voltage amplification is the result of the amplification of the tubes and the voltage

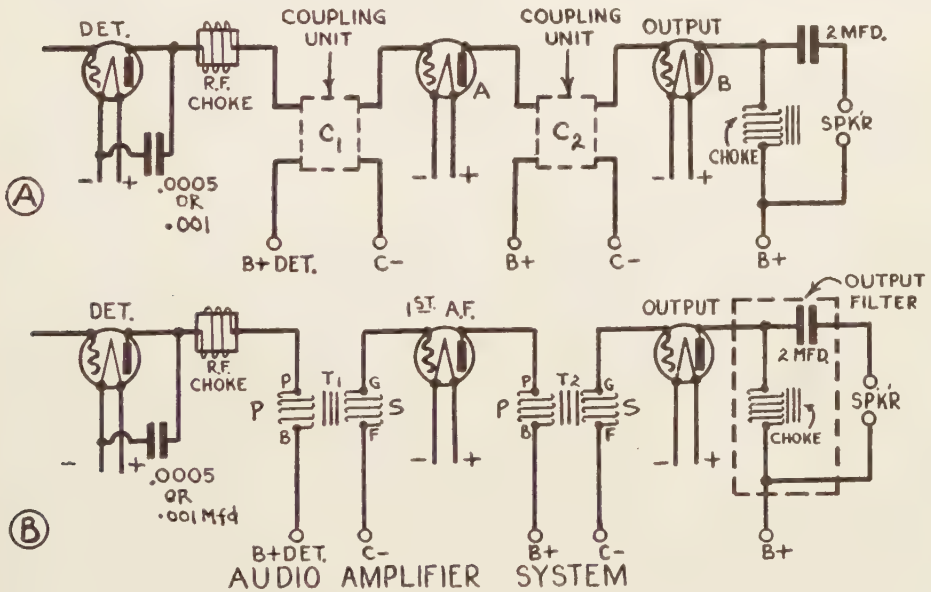


Fig. 161

step-up in each stage produced by the transformers. The amplification and frequency performance depends primarily on the transformer characteristics when the tubes are operated at their proper filament, plate and grid voltages. This is governed by the construction and materials of which the transformers are made.

216. **AUDIO TRANSFORMER:** The A. F. transformer as shown in Figs. 162 and 163 consists of a primary and a secondary coil insulated from each other and from the laminated steel core on which they are placed. The varying plate current of the detector tube flowing through the primary coil of the first transformer (Fig. 161B) sets up a varying magnetic field which travels easily through the coil and links and unlinks with the secondary coil, inducing a varying voltage in it. This induced voltage in the secondary is applied to the input or grid circuit of the following tube. The tube amplifies the varying voltage and transfers the signal to the next transformer primary, in the form of a varying plate current of

amplified magnitude. This transformer acts in the same manner as the first and its induced secondary voltage is applied to the input circuit of the last or "output tube." The output tube either feeds directly into the loud speaker or feeds into the loud speaker through an output filter, as will be explained later.

Evidently, it is desirable to produce as large an induced voltage as possible in the secondary of each transformer for a given primary voltage.

The secondary usually has more turns than the primary in order to step up the voltage. The usual ratios are between 2 to 1 to 4 to 1, although, as will be seen, the ratio is not the only factor governing the voltage step up. The primary winding P is placed in the plate circuit and the secondary S in the grid circuit of the following tube, Fig. 161B. The windings consist of many thousands of turns of about No. 40 or 44 enameled copper wire. The cores are laminated to reduce eddy current effects due to the constantly changing magnetic field. The shell type or "closed" core shown in Fig. 162 is used most because of the small amount of magnetic leakage between the primary and secondary. The primary is usually placed inside of the secondary, and if both coils are wound in the same direction the connecting leads are usually taken off in the order shown in Fig. 162. The inside end of the primary (P) goes to the plate of the vacuum tube, the outside end (B+) goes to the B+ battery. The inside end (F) of the secondary goes to the negative filament or negative "C" battery terminal and the

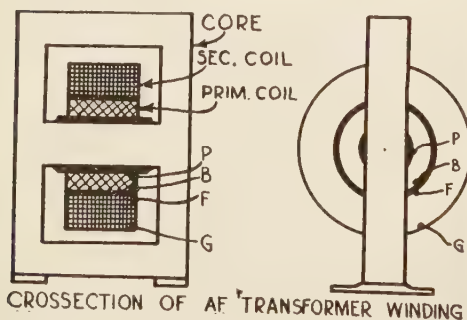


Fig. 162

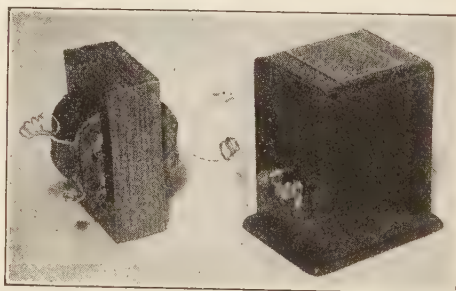


Photo Courtesy Pilot Radio & Tube Corp.

Fig. 163—A. F. Transformer
Unmounted and in Case

outside end (G) goes to the grid. This keeps the grid and plate terminals as far apart as possible, thus lowering the effective capacity across the coils. Fig. 163 shows a high grade transformer unmounted, and when mounted in a soft iron protective case. The markings which appear on the terminals of A. F. transformers are to assist in connecting them up. Thus the terminal of the primary which goes to the plate of the tube is marked "P". The other end, which goes to the B+ battery, is marked "B+". The end of the secondary which goes to the grid of the following tube is marked "G", and the end which goes to the negative "C" battery is marked F—.

217. **ANALYSIS OF A. F. AMPLIFYING STAGE:** Fig. 164A shows a single stage of transformer coupled A. F. amplification. Let us study this in detail in order to understand what happens. The transformer is connected

between the two tubes in the usual way. E_1 is the A. F. voltage applied to the input of the stage. This is equivalent to an A. F. voltage of μE_1 (μ is the amplification constant of the tube) in the plate circuit of the first tube A, tending to cause the A. F. component of the plate current to flow. The plate-to-filament path in the tube acts like a resistance equal in value to the plate impedance of the tube (12,000 ohms for a 201-A type tube with 90 volts on plate). The primary of the audio transformer, consisting of thousands of turns of wire wound on an iron core, has appreciable inductance, so that it presents an A. C. impedance to

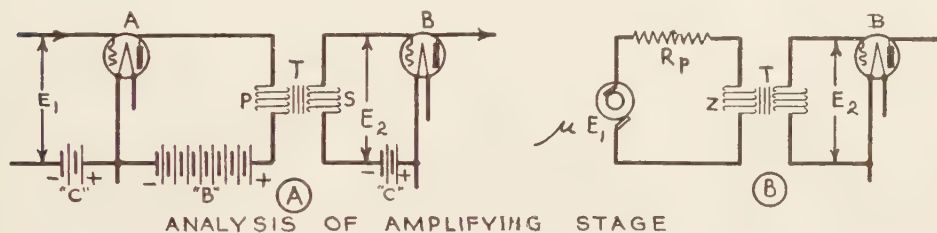


Fig. 164

the varying A. F. plate current. These facts can be used to draw the simplified equivalent circuit diagram of Fig. 164B, where μE_1 is a source of A. F. voltage tending to send current around the circuit through the plate resistance R_p , and the transformer primary impedance Z . This current, flowing through R_p and Z , produces a fall of potential across each, the sum of the two being equal to μE_1 . As the vacuum tube is a voltage operated device (changes in grid voltage producing changes in plate current) we are interested in getting as large a voltage E_2 across the input of the second tube as possible. This means that we must apply as large a voltage across the primary of the transformer as possible. The voltage μE_1 available in the circuit will, of course, divide itself between R_p and Z , proportional to their relative values of impedance. Thus if R_p equals Z the voltage divides equally between them. If Z equals one-half of R_p then the voltage across Z will be one-half that across R_p . If Z is infinitely large, the entire voltage μE_1 will appear across Z . This is evidently the ideal condition, for then the total voltage μE_1 applied to the primary of the transformer would result in the maximum value for E_2 . (We have the same condition in R. F. amplifiers.) However, this is impossible to attain in practice because of the difficulty in constructing a primary coil having the necessary number of turns for infinite impedance and also due to the fact that such a coil would have such a high direct current resistance, due to the large amount of wire, that a large proportion of the "B" battery voltage would be used up in it, leaving only a small voltage to act on the plate of the tube. The tube would then not be operating on the most desirable part of its characteristic curve. This sets the practical limit. Actually, if the plate load impedance is about three times the tube plate impedance, an amplification nearly equal to the μ of the tube is obtained.

218. DESIGN OF A. F. TRANSFORMERS AND LOGARITHMIC CURVES: Since the primary of the transformer is an inductance, its impedance

varies with the frequency, becoming greater as the frequency rises and decreasing as the frequency decreases. (See Article 27 in Chapter 2.) The signal voltage E_1 impressed on the tube may be of any frequency between 32 and 8000 cycles, corresponding to the range of frequencies concerned in the reproduction of speech and music. Practically, the result is that at the low frequencies at which the transformer impedance is low, very little of the total applied plate circuit voltage is effective across the transformer; most of it is across the tube. At the higher frequencies a greater proportion of it is applied to the transformer, because the transformer primary impedance is high. As a result of this, the low notes do not receive as much amplification as do the moderate and high frequencies, resulting in distortion of the program. Actually the high frequencies are reduced somewhat by the decrease of amplification due to the distributed capacity of the windings.

The amplification of a stage of A. F. amplification using such a transformer may be shown by curve A in Fig. 165. In order to study the audio frequency response curve more nearly under actual hearing conditions, a special method of plotting these curves is used. Instead

of making the distance along the frequency scale proportional to the frequency, it is made proportional to the logarithm of the frequency. The vertical scale is drawn proportional to the logarithm of the voltage amplification. That is all due to the fact that we hear logarithmically. The difference in pitch between two sounds as heard by the human ear corresponds to the logarithm of the ratio of their frequencies. Similarly, the ear's response

to differences in loudness are nearly proportional to the logarithm of the difference in pressure. A full orchestra playing at its loudest sounds only about sixty times as loud as when playing at its softest, although the amount of sound energy is a million times greater ($\log 1,000,000 = 60$). This fortunate provision of nature protects our ears against injury from very loud noises. Therefore, in order to get a true picture of the frequency characteristic from the viewpoint of the way the human ear responds to sound, the scales are plotted logarithmically.

The logarithm of a number is the power to which 10 must be raised to equal the number. Thus $\log 1000 = 3$, because $10^3 = 1000$. Similarly, $\log 45 = 1.653$ because $10^{1.653} = 45$. This common system of logarithms uses 10 for the base.)

The problem then is one of designing the transformer to have as large a primary impedance as possible at the low frequencies, for since the impedance increases with the frequency, there is no difficulty in obtaining high impedance at other than the low frequencies.

The impedance at low frequencies depends upon the inductance. The larger the inductance the greater the impedance. To get a large inductance a large number of turns of wire is required on the primary coil, and a core material of high permeability must be used. This makes the transformer more expensive.

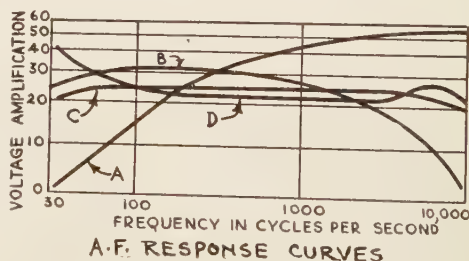


Fig. 165

If the voltage step-up property of the transformer is to be made available, the secondary must have more turns than the primary (in a 3 to 1 transformer the secondary has 3 times as many turns as the primary). Let us assume a 3 to 1 transformer. If the primary contains enough turns to have the proper impedance necessary to match that of the tube, the secondary will have 3 times as many turns and be very large and expensive. Also, the large number of turns of wire on both the primary and secondary coils will have a large distributed capacity (see Fig. 98 in Chapter 12). These will act as shunt condensers C_1 and C_2 , connected across these coils, as shown in Fig. 166. Since the reactance of a condenser decreases as the frequency is increased, the effect of C_1 is to allow the high frequency currents to easily pass through the condenser instead of through the primary coil. One effect of this is to partially short-circuit the high notes since these currents do not produce any magnetic field or secondary voltage. Condenser C_2 also has the effect of putting a load on the secondary coil, since currents flow around the secondary winding and through this capacity. The magnetic field of

these currents opposes the primary magnetic field and reduces the primary inductance and voltage transferred to tube B. The result is that the high distributed capacity in either of the windings cuts down the amplification of the high frequencies, and distortion results. Curve B (Fig. 165) shows the frequency response of a stage of A. F. amplification using a transformer of this kind. Notice that the response at

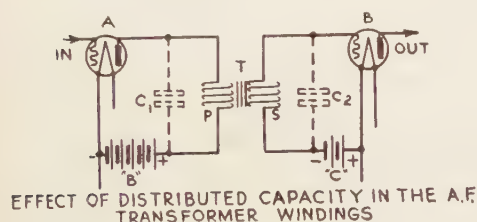


Fig. 166

the low notes has been improved greatly, at the expense of the high notes. (One manufacturer reduces the distributed capacity by winding the coils in helical fashion.) The size of the secondary coil could be kept down by making a 1 to 1 transformer, but then the amplification would be reduced.

It can be seen that a compromise must be made between primary inductance, turn ratio, and cost. The turn ratios of modern high grade transformer vary from about 2 to 1 to 4 to 1, $3\frac{1}{2}$ to 1 being a common value. The primary inductance is made large enough to reproduce the low notes well, without serious decrease in high frequency response due to distributed capacity. Curve C of Fig. 165 shows the frequency response of an A. F. amplifier stage using a high grade transformer. Notice the compromise between curves A and B. An idea of the characteristics of this transformer can be obtained from the following specifications: turn ratio 3 to 1, primary inductance 100 henries, primary resistance 3,700 ohms, primary impedance 19,000 ohms at 32 cycles, 626,000 ohms at 1000 cycles under operating conditions. Secondary inductance 900 henries, secondary resistance 10,000 ohms.

219. SIGNIFICANCE OF FREQUENCY RESPONSE CURVE: It is essential that the frequency response curve of any audio coupling unit should show the performance of the unit in actual use, that is, with its associated vacuum tubes and under operating conditions. A curve of a transformer, impedance coupling unit, resistance coupling unit, etc., when used with the testing device only, and

not in actual practice with the correct vacuum tubes and plate and grid voltages, is useless, since the performance will be different in actual practice, due to added tube capacities, etc. The plate resistance of the tube (which depends among other things, on the plate voltage and filament current) will affect the operation of the coupling unit. If this is a transformer, the load applied will produce marked changes. Considering all these factors, frequency response curves are without real value unless made under actual operating conditions.

220. TRANSFORMER RATIO: The effect of using transformers of various ratios on the total amplification of an A. F. stage (tube and transformer) is usually very misleading. We know from the foregoing discussion that a high ratio transformer is more desirable from the standpoint of transformer voltage step-up than one of lower ratio. But the advantage gained by the use of the higher ratio transformer depends upon how the higher ratio is obtained. Manufacturers put out a line of transformers of various ratios in which the number of secondary turns is the same for all transformers. Various ratios are obtained by changing the number of primary turns. Thus their 1 to 1 transformer has equal primary and secondary turns. Their 3 to 1 transformer has the same number of secondary turns but only one third as many primary turns. Obviously the 3 to 1 transformer has a higher step-up voltage in itself, but the impedance of its primary is so low compared to the plate impedance of the tube that the low notes are slighted and the amount of amplification lost through this poor match is greater than the amount gained in the transformer by the higher ratio. With such transformers it is sometimes found that an amplifier using 2 to 1 transformers produces more amplification and better quality of reproduction (due to the higher primary impedance) than one using 5 or 6 to 1 transformers of the same make.

The plate impedance of the detector tube is usually much higher than that of the amplifiers due to the lower plate voltage used on the detector. For instance, the plate impedance of a 201A tube used as a detector with 45 volts on the plate is about 18,500 ohms while the plate impedance of the same tube when used as an amplifier with a plate voltage of 135 volts and 9 volt negative "C" bias is 11,000 ohms. Thus if transformers of different ratios are to be used in a two stage amplifier, the transformer having the higher primary impedance should follow the detector tube, in order to match its plate impedance better. This is usually the lower ratio transformer, although not always the case, since some of the larger manufacturers are beginning to construct their transformers with a standard primary and vary the number of secondary turns to get various ratios. In the latter case the transformer of lower ratio should be used in the first stage.

221. LARGE SIZE TRANSFORMERS AND CORE SATURATION: The primary of the audio transformer has flowing in it the audio pulsating direct plate current of the vacuum tube. As shown in Fig. 115, Chapter 12, this can be considered as a combination of a steady direct current and an alternating current of audio frequency. The alternating signal current flowing through the primary coil produces the useful alternating magnetic field which induces a voltage in the secondary. The steady direct plate current produces a steady magnetic field which is of no practical use but which merely tends to magnetically saturate the core of the transformer, and cause distortion due to the decreased inductance of the coils.

(This is especially true when employing tubes such as the 112A type, which draw a heavy plate current (see Fig. 54).

This can be illustrated by curve No. 1 of Fig. 167, which shows an arbitrary magnetization curve for transformer steel. This shows the relation between the primary current and the amount of magnetism produced by this current. Suppose the steady plate current is 6 milliamperes, corresponding to point A on the curve and producing a steady magnetic field of 3000 lines of force in the core. Suppose further that the signal applied to the grid causes the current to fluctuate $+2$ and -2 milliamperes from this value, as shown by the signal wave and corresponding to points B and C. Then the flux varies from 4,000 lines to 2,000 lines, a total change of 2,000 lines, which link and unlink with the secondary coil, producing a secondary voltage. This is the condition where the core is of ample cross section

to prevent saturation. (However, the steady D. C. plate current of 6 milliamperes flowing through the primary coil may tend to permanently magnetize the core if certain special kinds of high permeability steel are used, resulting in unequal changes of magnetic field with changes of plate current.)

Now consider the case where a core of insufficient cross sectional area is used with the same windings considered previously. Curve No. 2 represents the magnetization curve for this condition. The transformer is now working on the curved portion of the magnetization curve. Notice that above 4 milliamperes the increase of magnetic field is not proportional to the increase of magnetizing current because of saturation. That is, nearly all of the molecules of the core metal have been magnetized by the steady direct plate current, so an increase in magnetizing force does not produce

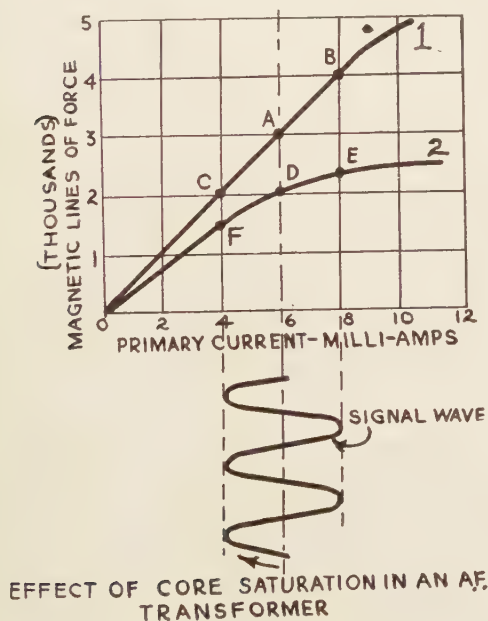


Fig. 167

much increase in magnetism. Now if the plate current fluctuates $+2$ and -2 milliamperes from its steady value of 6 milliamperes (points D, E, F), the magnetic field changes from 2,300 lines to 1,500 lines, a net change of only 800 lines. Thus the inductance of the primary is decreased and less voltage appears at the secondary of the transformer. Also, as the signal current varies about point D, the steel is not magnetized to as great a degree by the right hand half of the signal current wave as it is demagnetized by the left hand side of the wave. The voltage appearing across the secondary coil is proportional at any instant to the change in magnetism in the core at that instant, so it is evident that the secondary voltage wave will be distorted by the non-linear characteristics of the iron. This is sometimes called "hysteretic" distortion, as it originates in the hysteresis curve of the iron.

Hysteretic distortion, which may cause serious distortion of the wave form of the signal, is not indicated by the ordinary frequency response curve of Fig. 165. Thus, while an audio amplifier may have a perfect frequency response characteristic, excessive hysteretic distortion may make it a very poor, or worthless, amplifier when operated for the reproduction of speech or musical program. This is one phase of the explanation of the poor performance of some amplifiers which seemingly should give splendid results.

Saturation can be avoided by the use of exceptionally large amounts of iron in the cores. The increased amount of copper and iron used in modern high grade audio transformers is the result of a study of these factors. Of course, the cost has also increased. Some manufacturers use special nickel-steel alloys of very high permeability for the transformer cores, in order to obtain a high primary inductance. However, the danger of core saturation is greater with these materials on account of the increased magnetic field produced by a given steady plate current. The steady flux is decreased by some manufacturers by inserting a small air-gap in the magnetic circuit. This also decreases the primary inductance slightly, but helps solve the problem of saturation. A solution to this problem is the use of the shunt feed plate supply.

222. SHUNT FEED PLATE SUPPLY: The troubles arising from the effects of the steady direct plate current flowing through the primary of the audio transformer can be eliminated by keeping this current out of the winding and allowing only the A. C. component of the current to flow through. One way of doing this is by connecting a blocking condenser C in series with the transformer primary and supplying the steady plate potential to the plate of the tube either through a resistance R , as in Fig. 168A, or an audio choke coil L , as in Fig. 168B. Condenser C blocks the passage of steady direct current but is made of large enough capacity (2 to 4 mfd.) so its impedance to the passage of A. F. currents flowing through the primary winding of the transformer is very low. The resistance R (about 30,000 ohms), or the choke coil L (100 henries) block the A. F. currents (since they offer a high impedance to these currents), but allow the easy passage of the direct plate current. The path of the A. F. currents is shown by the arrows. This system gives slightly lower amplification and increases the cost of the amplifier, but presents a means for eliminating the distortion caused by the direct plate current.

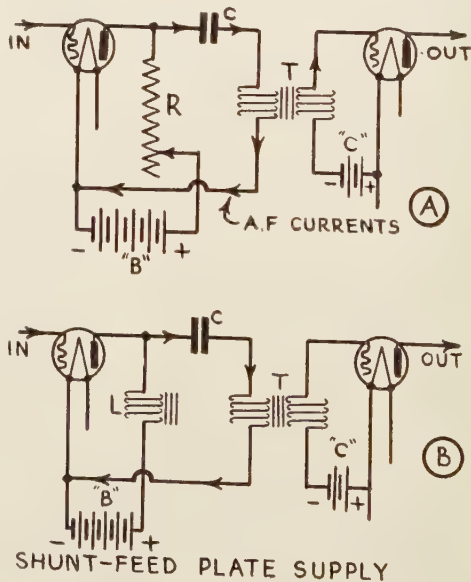


Fig. 168

223. CLOUGH SYSTEM OF SHUNT PLATE FEED: A recent improve-

ment in the shunt feed method of transformer coupling, known as the Clough system, is shown in Fig. 169. The D. C. component of the plate current flows through a resistance R of about 30,000 ohms (10,000 ohms for detector unit) which is connected as shown. The path of the A. C. component is through the condenser C and lower portion (primary) of an auto-transformer through the "C" bias voltage supply, to the filament circuit of tube B, and back to tube A, as shown by the arrows. Since the secondary of the auto transformer includes the whole winding, there is a step-up in voltage, depending on the position of the tap. This ratio is usually made about 4.5 to 1. The system is so arranged that when a "B" potential of 180 volts is used, the voltage drop through the 100,000 ohm detector plate resistor is just sufficient to leave about 45 volts available for the

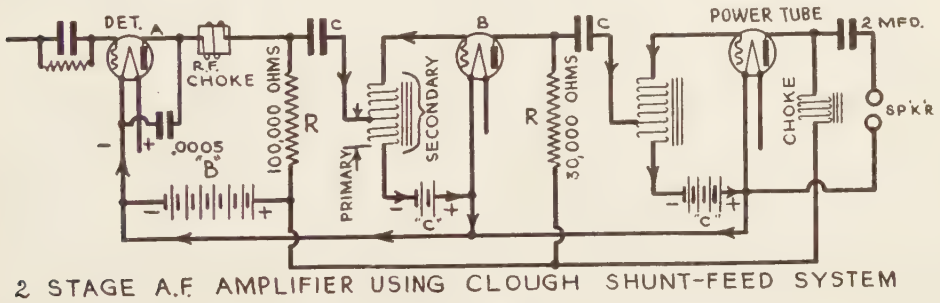
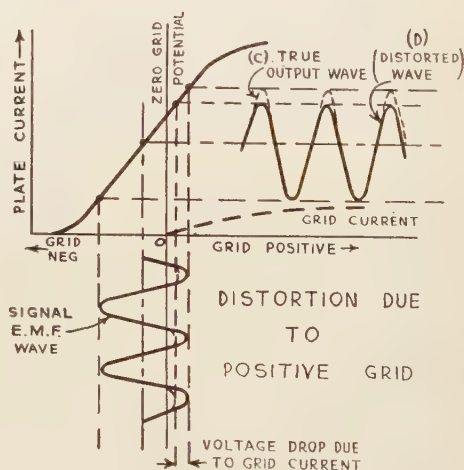
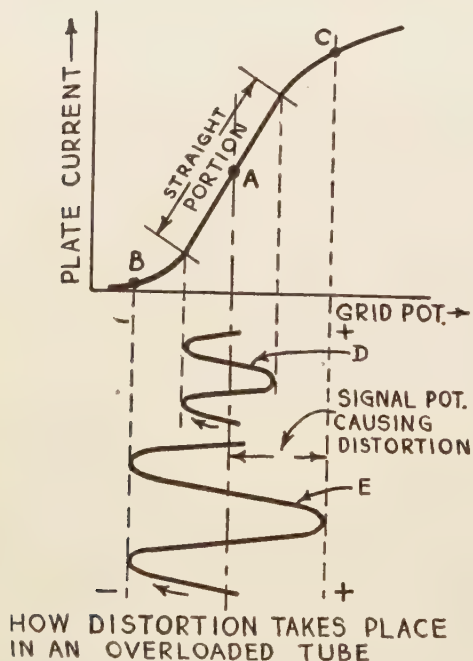


Fig. 169

plate, and the voltage drop through the 30,000 ohm plate resistor is just sufficient to leave about 135 volts available for the plate of the first audio tube when 201A type tubes are used. For tubes drawing different plate currents, different values of plate resistors can be used. This system gives a greater effective inductance for a given expenditure of copper and iron, due to the absence of the steady D. C. current in the primary. Therefore, for a given low frequency response the primary and secondary turns can be made less in number than in an ordinary transformer connected in the ordinary way, thus reducing the distributed capacity and improving the high frequency response. The low frequency response can be altered at will by using condensers of various sizes for C.

Provided the inductance of the primary of the auto transformer exceeds a certain critical value, determined by the lowest frequency to be reproduced by the amplifier, the condenser C can be chosen of such size as to have a reactance at the lowest reproduced frequency equal to the reactance of the primary. This produces resonance in the circuit at this frequency, and greatly increases the amplification at this frequency, with a rather sharp cut-off in amplification of frequencies below the resonance point. Fig. 169 shows a two stage amplifier of this type. The frequency response curve of this system is shown by curve D of Fig. 165. This is a case where a condenser has been used to produce resonance at about 30 cycles, to boost the low frequency amplification. The resistance, coupling condenser and auto transformer are available in commercial units enclosed in a case with proper terminals. Different units are used for first and second stages.

224. **TUBE DISTORTION—"C" BIAS:** Thus far we have considered only the distortion arising in the coupling medium of the A. F. amplifier. A consideration of the theory of the vacuum tube amplifier (Chapter 6, Fig. 51), shows that if equal changes of grid voltage are to produce equal changes of plate current, the tube must be operated at all times on the straight portion of its characteristic curve (see Fig. 170). That is, the mean voltage of the grid must be kept between the upper and lower bends of the characteristic curve, so that equal positive and negative waves of signal grid potential fall within the straight



Left: Fig. 170

Right: Fig. 171

portion and produce equal changes of plate current from the normal steady value. This is accomplished by connecting a "C" battery of proper voltage depending on the plate voltage and the tube used (see vacuum tube table Fig. 54), with its negative terminal to the grid return, and positive terminal to the negative leg of the filament (Figs. 51 and 169). This also reduces the "B" current consumption and results in a saving in the life of the "B" batteries or reduces the current drain on the electric "B" power supply unit.

It is not only necessary that the signal potential should at all times operate the tube on the straight portion of its characteristic curve but also the grid potential must at all times remain negative with respect to the filament. This means that all incoming signals impressed on the grid must merely make it more and less negative; but at no instant should the potential of the grid swing over the zero line and make the grid positive. It is possible for a tube to be operated so that a signal may operate the tube wholly on the straight portion of its characteristic

and yet make the grid positive, as shown in Fig. 171. The actual result which obtains as soon as the grid swings "positive" varies with the type of circuit, but the reason for the trouble is always the same. The grid, having a positive potential, acts like a plate and draws a grid current, as shown.

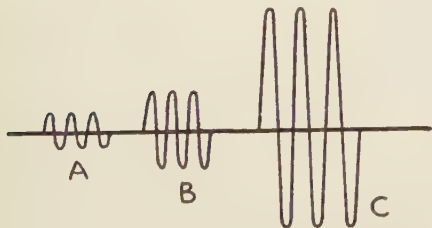
As soon as the grid goes positive and draws a grid current, this current must flow through the electrical apparatus in the grid circuit, and therefore there is a voltage drop in this. This voltage drop prevents the grid potential from swinging as far as it otherwise would. The signal amplified wave is then distorted and decreased on the positive half of the cycle. The dotted curve C in Fig. 171 shows what this amplified wave would look like if the grid did not go positive, and the solid curve D shows what it actually looks like due to the distortion. Volume and quality are thus reduced.

Selectivity in an R. F. circuit is materially reduced if the grid becomes positive, as the grid-filament circuit then becomes conductive and acts as an appreciable leak and high loss across the tuning condenser. Therefore it should be carefully remembered that any amplifying tube should be so operated that the grid will at all times be kept negative under the usual signal conditions. This is another reason for using the proper value of negative "C" bias. The "C" bias values given in Fig. 54 are the proper ones recommended by the tube manufacturers. Notice that the "C" bias value increases as the plate voltage is increased. This will be readily understood by referring to Fig. 47 in Chap. 5. The characteristic curves for the higher plate voltages fall above and to the left of those for the lower voltages. Therefore the normal operating point of the grid must be shifted to the left by using higher "C" bias voltages.

225. POWER TUBES: Any vacuum tube has a certain definite range over which its characteristic curve is straight (Fig. 170). If the signal voltage D is small enough so it produces grid potential swings which lie on the straight portion of the characteristic curve and which do not make the grid positive at any time, the tube itself will not cause distortion. Even if the grid is biased properly so that the normal grid voltage is, say at point A, the signal voltage caused by a very loud signal wave E may be so great that the grid voltage swings past the straight portion of the curve to points B and C, resulting in distortion, since unsymmetrical changes of plate current are produced. This is the usual case in the second A. F. stage when 201A tubes are used, and is known as tube overloading.

Fig. 172 may make this more clear. Assume that the signal e.m.f. input to

the first amplifier tube is represented by curve A. After passing through the first amplifier stage the amplified voltage applied to the second stage is as shown in curve B. If it passes through still another stage it becomes stronger, as shown in curve C. As each stage amplifies the voltages more, the amplitude of the signal e.m.f. may become so great that when it is impressed on the grid of the last tube it either extends beyond the linear portions of the characteristic curve (see Fig.



AMPLIFICATION OF SIGNAL.

Fig. 172

170) and therefore introduces distortion of the wave form, or it exceeds the grid bias and causes distorting grid currents to flow while the grid is positive. This is one of the limiting factors as to the number of stages of amplification of one kind which may be used.

Overloading of the radio frequency amplifying tubes rarely occurs, as the initial input signal voltages are exceedingly small. Overloading of audio tubes is common and has led to the design of special tubes, known as power tubes, designed to have a large portion of their characteristic curves straight, so they are able to handle greater signal voltages without this distortion. Among these are the 112A, 171A, 245, 210 and 250 type tubes. For ordinary home use the 171A or 245 will usually handle all the signal energy that can be comfortably used. For powerful amplifiers used for special purposes, the 210 and 250 type tubes can be used. The undistorted power output handling capacity of these various tubes at various plate voltages is shown in the table of Fig. 54. Power tubes are usually used in the last or output stage, and require a higher "C" bias voltage than 201A type tubes (see Fig. 54). Where more handling capacity than one tube alone can handle is required, two tubes are usually connected in push-pull, as explained later. The distortion caused by an overloaded tube is a distortion of wave form, somewhat similar to hysteretic distortion caused by transformer core saturation.

226. **OUTPUT FILTER:** As the plate current of power tubes is much greater than that of general purpose tubes, it is generally advisable to protect the delicate loud speaker windings from this current when output power tubes are used by employing either a 1 to 1 ratio output transformer (Fig. 173A), or the choke coil-condenser combinations of Figs. 173B and 173C. This keeps the direct current of the plate out of the speaker windings (see Fig. 115 in Chap. 12) and allows only the A. C. component to flow through, as shown by the arrows. It also

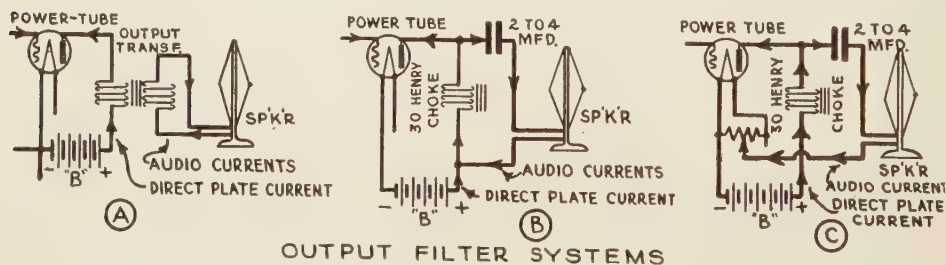


Fig. 173

prevents the direct current from tending to de-magnetize the permanent magnet of the ordinary loud speaker if it were sent into the winding in the wrong direction. The choke and condenser method is usually preferable, since with the transformer method the transformer may introduce distortion due to poor impedance match with the power tube, core saturation, etc. The connection of Fig. 173C is preferred since it returns the varying audio currents directly back to the filament and keeps them out of the "B" power supply device, thus preventing undesirable coupling. If the filament of the power tube is operated on D. C. the speaker

return lead can be brought directly to the negative filament terminal. If the filament is operated by raw alternating current from a transformer, the speaker return should be brought to the electrical center of the filament. This can be done by either returning it to a center tap on the transformer filament winding or to the center tap of a fixed resistance connected across the filament as shown in Fig. 173C. For 2.5 volt filament tubes it should be about 30 to 50 ohms, for 7.5 volt tubes it should be about 75 ohms. Fig. 174 shows a center-tapped resistance moulded in Bakelite and made especially for this purpose.

The output filter also serves another purpose besides acting as a protection for the speaker. The loud speaker, which does the actual reproducing of sound, is an energy or power operated device, that is, power must be supplied to it to

set a large amount of air in motion to produce sound waves. This power is obtained from the last audio tube (output tube), and the undistorted amount of power that the output tube can supply (see Fig. 54 for undistorted power outputs of various tubes).



Fig. 174—Center Tapped Resistance

Obviously it is desired to get a maximum transfer of power from the output tube to the speaker. It can be proven (see any text on electrical engineering), that in electrical circuits in which a transfer of power is involved, maximum transfer of power occurs when the impedance of the circuit or load which is

receiving the power equals that of the source. Where the source and load are of widely differing impedances, a transformer or other device can be used to match the load impedance to the impedance of the source. For instance, the plate impedance of a 250 type tube with 450 volts on the plate and "C" bias of 84 volts is 1800 ohms. If this supplies power to a Western Electric 540 AW, cone speaker, whose average impedance is about 4000 ohms, some impedance adjusting or matching device must be inserted between them for maximum transfer of power. In the dynamic type of speaker the impedance of the moving coil is very low and an impedance matching output transformer is always used between the power tube and the speaker. This is usually incorporated in the speaker itself, so that the speaker terminals can be connected directly to the power tube output terminals.

227. DETECTION OF TUBE DISTORTION: Distortion arising in the tubes of an amplifier due to overloading or grid current can be detected very easily by connecting a direct current milliammeter (range depends on plate current of tube tested) in the plate circuit of the tube to be tested, as shown in Fig. 175. With a strong signal tuned in on the receiver the needle of the milliammeter will not fluctuate more than 10% from its normal steady value if tube distortion is absent (since the meter is unable to follow the individual audio frequency current variations and if these variations are exactly equal up and down, there is no movement).

If tube distortion due to incorrect "C" bias voltage is present, the needle will fluctuate violently when loud notes are played. If the "C" bias voltage is insufficient (Fig. 170), the signal voltage drives the grid positive, or over the positive bend of the curve, thus cutting off the maximum peaks of the plate current, resulting in a lower average plate current manifested by "downward" dips of the

milliammeter needle on loud notes. If the "C" bias voltage is too high, the grid voltage is driven over the negative bend of the curve cutting off the minimum peaks of the plate current resulting in a higher average plate current and *upward* kicks of the milliammeter needle. If the needle kicks both upward and downward from the normal position, it indicates that the tube is overloaded, as the grid-voltage swing extends over both bends of the curve. The remedy usually is the use of a power tube with greater handling capacity (see Fig. 54).

228. VOLUME CONTROL:

Volume control of the complete receiver should usually be secured in the R. F. stages ahead of the detector. If a volume control is placed in the audio amplifier alone it is possible that both the detector and first R. F. stage are being overloaded, while the volume control reduces the output at the loud speaker to a comfortable intensity. If a volume control is desired in the audio amplifier for any reason, it should take the form of a variable high resistance potentiometer of about 500,000 ohms placed across the secondary of the first A. F. transformer, thus shunting it (Fig. 176). By moving the arm, any portion of the total secondary voltage (which is applied across the whole potentiometer) can be applied to the grid of the tube. Resistors of 5,000 to 750,000 ohms are sometimes shunted across the secondaries of poor transformers to flatten out the frequency response curve. A decrease in amplification results from this.

Volume control should not be obtained by reducing the filament voltage of the A. F. amplifier tubes, as this increases the plate impedance, resulting in inefficient impedance match between tubes and transformers, and also brings the upper bend of the tube characteristic curve down lower due to saturation of the tube reducing the straight portion. This reduces the grid voltage swing allowable for undistorted reproduction, resulting in distortion in the tubes of loud signals. Fixed ballast resistors are usually used in the filament circuits of A. F. amplifiers.

One volume control scheme which possesses many advantages is to have two volume control units mounted on the same shaft but insulated electrically from each other. One of the units is connected in the R. F. part of the receiver for volume control and the other is connected across the secondary of the first audio transformer. By this means the amplification of both the R. F. and A. F. amplifiers is decreased or increased simultaneously. This is especially useful in A. C. tube electric sets where most of the hum originates in the audio amplifier or detector. When reducing the volume with a control in the R. F. stages only, the hum remains of the same intensity and thus the set appears very noisy when playing at low volumes. By reducing the A. F. amplification at the same time as the R. F. amplification is reduced, the hum noises are reduced proportionately and the operation of the set is more quiet.

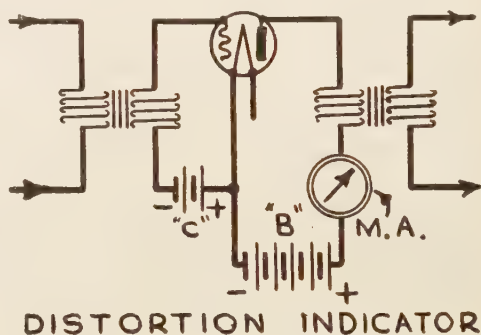


Fig. 175

229. **COMPLETE SET:** Fig. 176 shows the complete wiring diagram for a single control six tube set using two stages of tuned R. F. amplification, detector and two stages of A. F. amplification, with 171A power tube. The volume control resistance shown after the first A. F. transformer is optional. Zero plate reactance stabilization is used. Evidently a transformer coupled A. F. amplifier can be added to any of the R. F. amplifier and detector circuits already studied.

The overall frequency characteristic of an amplifier is frequently quite dissimilar to the characteristics of a single stage. This is especially true of transformer or impedance coupled A. F. amplifiers and is probably due, in most cases, to coupling in the plate supply. Regenerative effects are thereby introduced into the circuit, which may produce considerable change in the frequency characteristic. This can be avoided by careful design of all circuits, and if necessary, by the use of an audio frequency choke and by-pass condenser in each stage to keep the A. F.

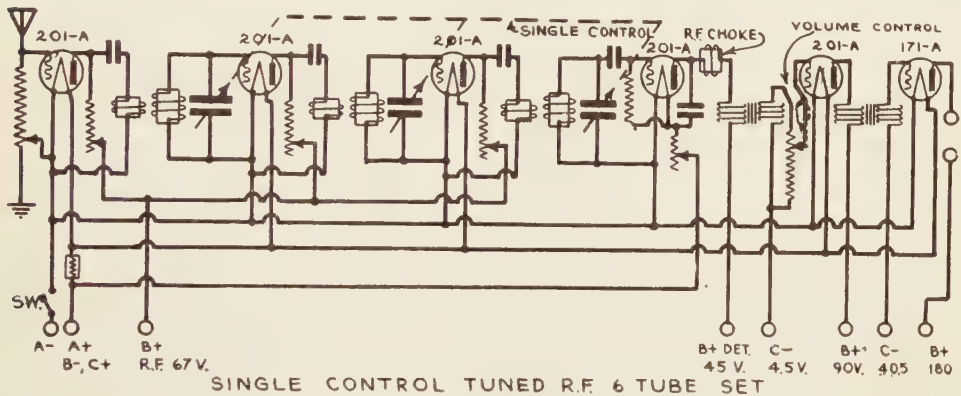


Fig. 176

currents out of the plate supply system. A similar solution was mentioned in connection with R. F. amplifiers.

230. **RESISTANCE COUPLED A. F. AMPLIFIERS:** The resistance coupled amplifier (Fig. 177) employs resistances in the plate circuits of the tubes with condensers to couple the plate and grid circuits of successive tubes together. The action in the first stage is typical of all the rest. The varying plate current I_p of the detector tube, flowing through plate resistor R_1 (about 100,000 ohms) produces a varying voltage drop across it equal to $I_p \times R_1$. Since the voltage of the plate battery is constant, this makes the *potential* of point A vary in exact accordance with the plate current variations. Now point A cannot be connected directly to the grid of the second tube, as a large positive grid bias due to the "B" battery would thereby be put on it. This would cause a grid current to flow and cause distortion, and also probably damage the tube due to the heavy plate current set up. It is removed by placing a blocking condenser C_1 between point A and the grid. If this condenser has good insulation it presents practically infinite impedance to the continuous (or direct) voltage, but allows the alternating audio frequency signal voltages to go through. The presence of this blocking condenser necessitates that the grid be connected to the filament through a high resistance

R_2 in order to provide a leakage path for the negative charges which would otherwise accumulate on the grid and block the operation of the tube. A negative grid bias may also be secured by connecting R_2 either to the minus side of the filament or to a "C" battery. The alternating voltage across R_1 is thus impressed between the grid and filament (through the battery circuits) of the second tube. The following stages are similar excepting that different resistor values are usually used.

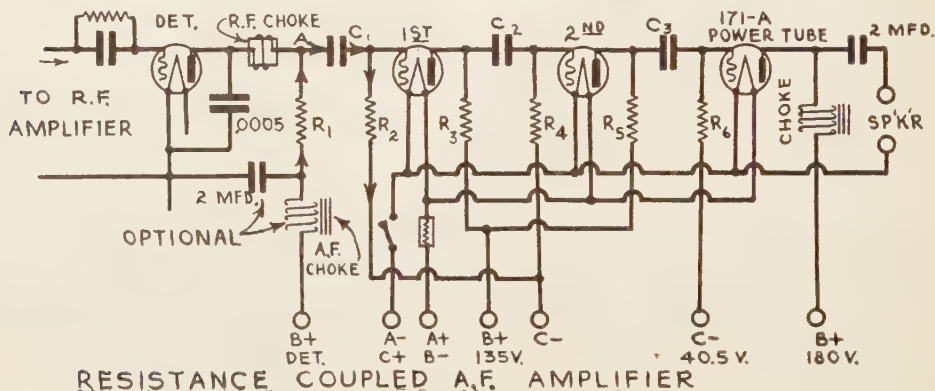


Fig. 177

As there is no voltage step-up in the coupling resistors, all of the amplification is produced by the vacuum tubes. This makes it necessary to use more stages for a given amount of amplification than when transformer coupling is used. A three stage resistance coupled amplifier produces about the same amplification as a two stage transformer coupled amplifier. The amplification can be increased by employing high mu tubes, such as the 240 type, which have a high amplification constant. Theoretically the plate resistors should be as large as possible, for the amplification per stage is proportional to the ratio of this resistance to the total plate circuit resistance. However, this resistance cannot be increased beyond certain practical limits, for the voltage applied to the plate of the tube is less than the "B" battery voltage by an amount equal to the IR drop through the resistor. If the resistor is made too large, abnormally high "B" battery voltages are necessary in order to apply enough voltage to the plate of the tubes to operate them at the proper points on their characteristic curves to prevent distortion.

Since the plate resistors are pure resistances they are not affected by changes of frequency, so they do not introduce frequency distortion in the amplifier. The blocking condensers however, can be a source of serious frequency distortion due to the fact that their impedance varies with the frequency. Thus the impedance of a .01 mfd. condenser is about 505,000 ohms at 30 cycles and 5000 ohms at 3,000 cycles. This varying impedance prevents the low frequency currents from getting through as easily to the grid circuit, and being amplified as much as the high frequency currents. Also, the blocking condenser and grid resistor form a circuit which requires a definite time for discharge of the negative charge on the grid. Unless this time constant is sufficiently short, the grid will usually block on strong signals resulting in a gurgling sound in the amplifier. This can be corrected in most

cases by careful choice of the proper plate and "C" bias voltages. The amplification of a resistance coupled amplifier can be made substantially uniform for all audio frequencies provided the handling capacity is reduced somewhat. The amplifier is cheap to construct and the plate current drain is light, but the plate voltage supply must be high.

231. SIZES OF RESISTORS AND CONDENSERS: The sizes of resistors and blocking condensers used vary with the types of tubes employed. High μ tubes are best, with a power output tube. For 201A tubes, plate resistors of 0.1 megohm, blocking condensers of 0.01 to 0.1 mfd., and grid resistors of 1 megohm first stage, 0.5 megohm second stage 0.25 megohm last stage with a 171A power tube output will be found satisfactory. For the 240 type high μ tubes, a six megohm plate resistor for the first stage and a one megohm plate resistor from the second stage is better, with 1 megohm grid resistors. A plate voltage of 180 volts is applied to each stage. Too low a value of grid resistor cuts down the volume. Too high a value causes blockings on strong signals. Too low a value of blocking condenser results in suppression of the low frequencies. If too large a condenser is used, it takes an excessive period to completely discharge, with the result that the high frequencies at least are not reproduced faithfully due to blocking of the grid. Too low a value of plate resistor results in poor impedance match with the plate circuit of the tube and low amplification. Too high a value results in excessive IR drop in the resistor, with necessity for the use of high "B" battery voltages in order to get the necessary amount of plate voltages at the tube. Thus compromises must be made.

The resistors should be of high quality and of permanent resistance value. The blocking condensers should have high insulation resistance, for faulty insulation will allow some of the plate potential to leak through it to the grid of the next tube, causing distortion or complete inoperation. Fig. 177A shows a commercial form of resistance coupling unit which consists of a Bakelite base which contains the coupling condenser. The plate and grid resistors are held in metal clips which

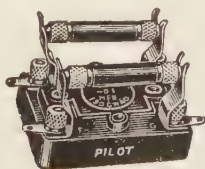


Fig. 177A—Resistor Coupler Unit



Fig. 177B—Wire Wound Plate Resistor

also serve as connections. Several units of this kind can be wired up to form a complete amplifier.

When resistance or impedance coupled amplifiers are operated on weak dry batteries or on socket power operated "B" battery eliminators, trouble may arise due to coupling between the stages, due to the high internal resistance of these devices. This makes itself evident by the setting up of low frequency oscillations which sound like a motorboat engine when reproduced by the loud speaker. This action is popularly known as "motorboating."

power unit. The value of the resistance may be anywhere from 10,000 ohms to 100,000 ohms for best results, depending upon the characteristics of the receiver and power unit. A variable resistor is suitable. Since the resistor is in series with the B+ detector lead, a slightly higher plate voltage will have to be used to compensate for the IR voltage drop in the resistor.

233. IMPEDANCE COUPLED A. F. AMPLIFIER: In the impedance coupled amplifier (Fig. 179) the plate resistors are replaced by inductance or impedance coils. Each coil consists of thousands of turns of wire wound on an iron core. The resistance of these coils to direct current is comparatively low, but the opposition or impedance offered to currents of audio frequency is very much greater on account of the inductive effect. Thus the direct current component of the plate current is not opposed very much by the low D. C. resistance of the choke coil windings, so comparatively low "B" battery voltages can be used. The impedance offered to the A. C. component however is very much higher so that an effective match with the plate impedance of the tube is secured if chokes of sufficiently high inductance are used. The impedance varies with the frequency just as in the case of the transformer primary, so that large impedances must be used if the low frequencies are to be amplified. The effect of the blocking condenser and grid leak are the same as for the resistance coupled amplifier. As no voltage step-up is secured in the impedances, the amplification per stage is lower than that of transformer coupling, so usually three stages are employed, with high mu tubes. Motorboating can be eliminated by the methods previously described.

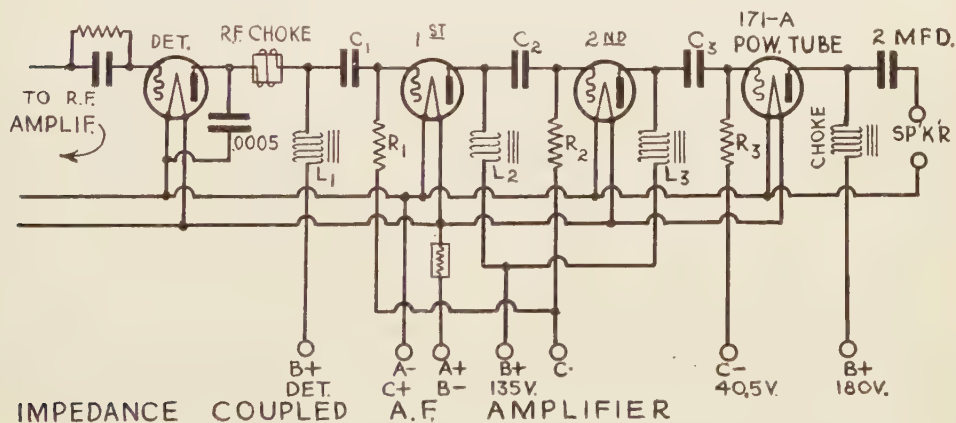


Fig. 179

234. AUTOFORMER IMPEDANCE COUPLING: Some voltage step-up in the impedance coil can be obtained if it is connected up as an auto-transformer (Fig. 180), so that the plate current flows through only part of the winding (usually 2/3). The varying current induces a voltage in the remaining part of the winding, and the total voltage is applied to the grid circuit of the following tube. The circuit now possesses the voltage step-up features of a circuit employing a two winding transformer, except that the blocking condenser and grid leak

with their disadvantage are still required. Auto-transformers can be built with much less wire and a smaller core to handle the same power and to have the same ratios as two winding transformers. By using well designed auto-transformers, proper blocking condensers and grid leaks, and a high μ tube as in Fig. 180, a two stage auto-transformer coupled amplifier may be built, having excellent frequency characteristics and about the same volume as the ordinary transformer coupled amplifier. It must be remembered that the position of the plate tap P is determined by the fact that the portion of the winding between P and B must have sufficient inductance to match the plate impedance of the tube at the low audio frequencies.

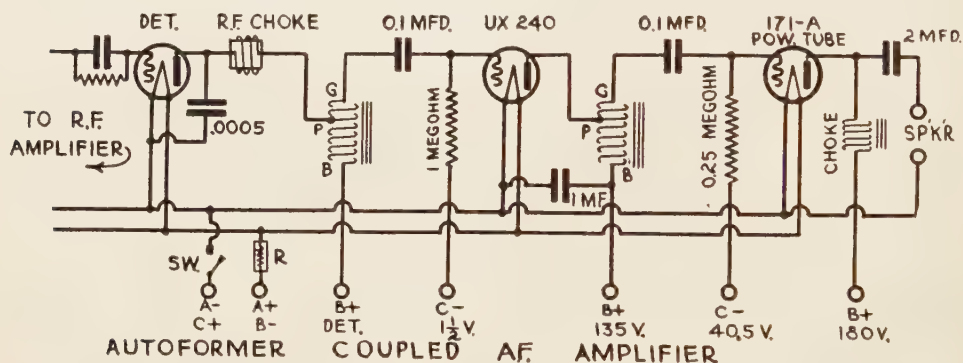


Fig. 180

235. DUAL IMPEDANCE COUPLING: Another arrangement which has many of the advantages of the ordinary impedance coupled amplifiers, with the additional advantage of giving higher voltage ratios, is known as dual impedance coupling. As shown by a single stage of Fig. 181, two windings having a 1 to 1 ratio are arranged on a single core, with a blocking condenser connected between them. Instead of the usual leak resistor we have an impedance coil. An electro-motive force is introduced into the leak impedance by the mutual inductance between the plate coil and the impedance coil. At the same time they are arranged so the capacity between them is very small. The extra voltage introduced into the grid circuit makes the total amplification greater than for straight impedance coupling with the advantage that strong signals do not block the grid. Very good reproduction is secured if the plate coil has an inductance of at least 100 henries, and a blocking condenser of about 0.1 mfd. is employed. In some dual impedance coupling units very good low-note amplification is secured without using very large coils and cores, by so determining the inductance of the plate and grid coils and the capacity of the coupling condenser that the entire combination tunes or resonates at about 30 cycles. The result is that the amplification of these low frequencies is unusually good. High μ tubes are usually employed in a dual impedance amplifier.

236. IMPEDANCE GRID LEAKS: In resistance and impedance coupled A. F. amplifiers impedance grid leaks can be used to great advantage instead of

pure resistances, especially in the last stage. An impedance grid leak is a fairly large coil wound on an iron core. It offers very little resistance to the discharge or leaking current, but offers a very high impedance path to any audio frequency, thus preventing shorting of the input side of the tube. A pure resistance offers just as great a leakage resistance to direct currents as it does to audio currents. An impedance grid leak is especially useful in the last audio stage where blocking action is liable to take place on strong signals, when ordinary resistors are used. They can be employed in any of the amplifiers described, in place of the grid resistors shown. They are of course more expensive than the simple resistors.

237. **COMBINATION COUPLINGS:** Some amplifiers are built with combinations of the coupling devices described, in order to secure certain desirable characteristics, such as a compromise between the well known high step-up of one, with the supposed high quality and power handling capacity of another. One popular combination is that of one stage of transformer coupling and two stages of resistance coupling. Care should be exercised in the use of such combinations, in order to secure desirable results. The proper relative order of the stages should be considered, to prevent overloading. In a combination of transformer coupling with any other type of audio frequency amplification, the transformers should be in the last stages, and the transformer with the highest ratio should be the last one. This tends to prevent overloading of the next to the last tube. Combination amplifiers also show a decreased tendency to motorboat, since the phase of the transformer stage can be reversed by reversing either the primary or secondary connection.

238. **PUSH-PULL AMPLIFICATION:** When a large amount of volume

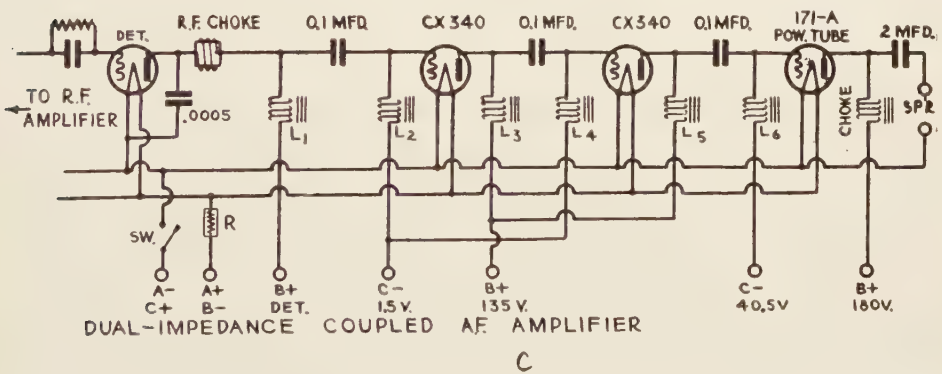


Fig. 181

is required from a radio set or loud speaker, the set must amplify the signal sufficiently to produce the required signal energy to be delivered to the speaker. This is a matter of designing a number of amplifier stages with the proper gain per stage, etc. The last audio stage in the audio amplifier must handle the comparatively large amount of power delivered to the speaker—and should handle it *without distorting the signal frequency or voltage variations in any way*. Large single power tubes such as the 210 and 250 tubes can be used to handle this power,

but the use of these tubes in home receivers results in unnecessary increased cost and complication of the "B" power supply unit since they require high plate voltages and draw large plate currents.

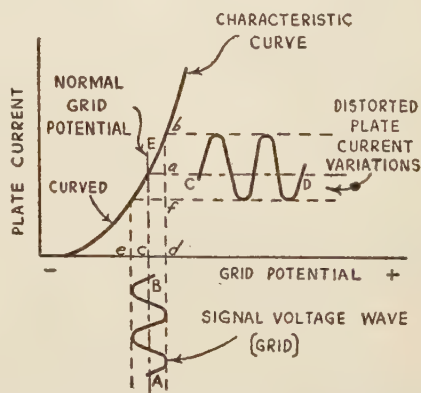
One solution to this problem is to use two smaller power tubes connected to the popular push-pull fashion, as shown in the simplified diagram of Fig. 182C. This combination has a greater undistorted power handling capacity than that of one tube alone. The push-pull connection, invented by Colpitts, also prevents second harmonic distortion, as will be explained later. It may be said then, that it has become popular because by its use two small tubes can be made to handle as much power without distortion or overloading as one larger tube.

The use of the smaller tubes reduces the cost of the "B" power supply unit, because they operate with lower plate voltage and plate current drain. The reliability and the maintenance cost are also reduced since the filter condensers, insulation, etc., are less liable to break down in "B" power units designed for 180 and 250 volts (for 171 and 245 tubes) than in units designed to operate at 450 volts or more (210 and 250 tubes).

When a vacuum tube is working into a low impedance (such as the primary of a transformer, a choke coil, etc.) in its plate circuit, its grid voltage-plate current characteristic curve is not straight, as has been assumed for simplicity in the "static" characteristic curve of Fig. 51 (Chap. 6), but is slightly curved, as shown in Fig. 182A.

In previous discussions of the action of the vacuum tube it was assumed for simplicity that the voltage existing between the plate and filament of the tube is kept constant in value. Under actual operating conditions, this is not the case. The "B" battery or "B" power unit supply voltage is constant but the actual plate-filament voltage is equal to the "B" voltage minus the drop in voltage occurring in the impedance of the device connected in the plate circuit of the tube, due to the plate current flowing through it. This device may be a resistor, the primary of a transformer, or a choke coil. As the plate current of the tube varies due to the incoming signal, this voltage drop also varies, since it is equal to the constant "B" supply voltage minus this voltage drop. Therefore, as the grid voltage varies, the plate filament voltage will also vary. Under these conditions the characteristic of the tube assumes the curved shape shown in Fig. 182A. The less this external impedance is the more nearly the tube characteristic conforms to the straight line form of Fig. 51 (Chap. 6).

The curve of Fig. 182A is commonly referred to as the "dynamic" characteristic of the tube because it is the characteristic of the tube under actual operating conditions.



ACTUAL DISTORTED AMPLIFICATION
DUE TO CURVED CHARACTERISTIC

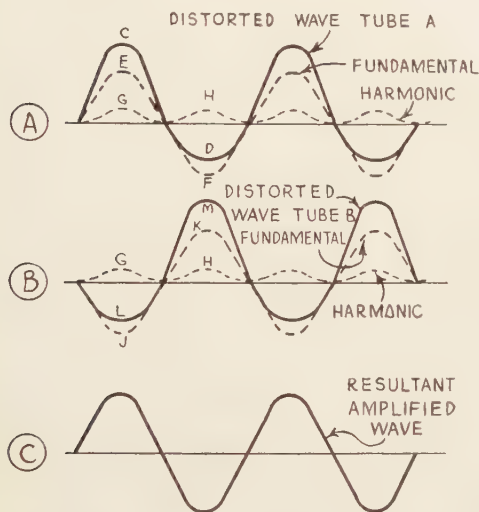
Fig. 182A

This condition exists especially in an output tube of an audio amplifier, where the tube is feeding into a low impedance load, usually the output choke, output transformer, or the loud speaker. The curved characteristic causes the output of the tube to be distorted, that is, the current variations in the plate circuit (curve

C D Fig. 182A) are not exact reproductions of the grid voltage variations (curve A B).

Thus, in Fig. 182A, if the signal voltage applied to the grid varies about the steady normal value E, the increase "a b" in plate current due to the decrease "c d" in negative grid potential is greater than the decrease "a f" in the current caused by an equal increase "c e" in the negative grid potential. This gives rise to the lop-sided curve "C D" and distortion. By a mathematical series known as Fourier Series, this distorted wave form (curve "C D") can be resolved into several components of various frequencies. (This discussion is too mathematical to be presented here.) One of these is the fundamental frequency (curve E F Fig. 182B-A) which indicates that at least the pitch of the original note will be preserved.

The other frequencies are the second



SECOND HARMONIC DISTORTION
CORRECTION BY PUSH-PULL AMPLIF.

Fig. 182B

harmonic (double frequency curve G H) and others which are so weak as to be relatively unimportant.

These frequencies, which were not present in the original tone, are added to those that were present, and distortion occurs in the reproduction, making the reproduced sounds different from the original sounds. Thus, if a pure undistorted 100 cycle note were applied to the grid of a vacuum tube, we would find that in the output there would appear a strong 100 cycle note and in addition some weaker (harmonic) notes of 200 cycles, 300 cycles, 400 cycles and so on. The weaker these "harmonic" frequencies are, the less is the distortion.

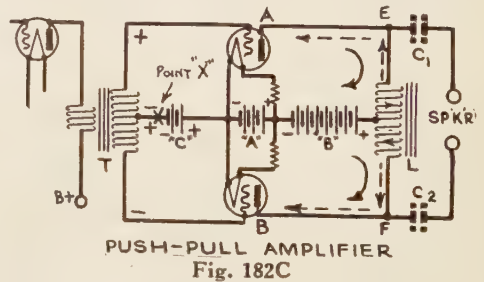
This form of distortion is known as frequency distortion and can also be caused by improper design of audio transformers, where the transformer is worked near the magnetic saturation point or bend of the magnetic curve as shown in Fig. 167. As will be shown, a properly designed and operated push-pull amplifier overcomes these sources of distortion, and permits of about three times the undistorted power output that is possible with a single tube of the same type and operated at the same voltages.

Fig. 182C shows a circuit diagram for a conventional stage of push-pull amplification. The input transformer T has the usual primary winding but the secondary is tapped at the center point. (In some push-pull input transformers

the primary and secondary coils are interwound.) The secondary has a greater number of turns than the primary, thus providing a step-up in voltage (usually 2 or 3 to 1). The two outside terminals go to the grids of the tubes. The center tap goes to the negative terminal of the "C" bias voltage supply (in this case a "C" battery). As each half of the secondary is connected to a separate tube, the induced signal voltage in the secondary of the transformer T is divided, each tube receiving an input grid voltage equal to only half the signal voltage. This point is important for it means that two tubes in push-pull can handle twice as much input signal voltage, without operating on the bend of the characteristic curve, as one of these tubes alone can.

Suppose that at a certain instant, the voltage induced in the secondary of the input transformer T is such that the grid of the top tube "A" is positive with reference to the center-tap of the transformer secondary, and the center tap is equally positive with reference to the grid of the lower tube "B." This does not mean that the grid is "positive" with reference to its filament, for in this event distortion would be produced due to the flow of grid current. The "C" battery takes care of this. It merely means

that the grid is more positive, or less negative than the center tap. Another way of putting this, is that one alternation of the signal impulse makes the grid of tube "A" less negative than the normal grid bias voltage and the grid of tube "B" more negative. The next signal impulse alternation does the reverse. There will then be an increase in current through the plate circuit of



PUSH-PULL AMPLIFIER
Fig. 182C

tube "A" and a decrease in plate current through tube "B." The output of each tube is passed through half the winding of an output choke L (or half the primary winding of an output transformer T as in Fig. 262. This is wound with a center tap so that the plate current in the upper half of the winding (Fig. 182C) flows in a direction opposite to that in the lower half of the winding. Therefore the magnetic field produced in the steel core by the upper half of the winding is in the opposite direction to that produced in the lower half. Therefore an increasing plate current in the upper half of the winding tends to increase the magnetic field produced by it and the simultaneous decrease in plate current through the lower half of the winding tends to decrease the field produced by it. Consequently the opposing force of this latter field is lessened and there is a greater resultant field in the core. Therefore the effect of an increasingly negative grid potential on one tube and a simultaneously decreasing negative grid potential on the other tube due to the signal, is additive in the output coupling device.

If the two tubes are exactly similar and operating at the same filament, grid and plate voltages, their direct plate currents will be equal, and since they flow in opposite directions in the split winding, as shown by the arrows with dotted lines in Fig. 182C, the magnetic fields due to the *steady normal plate current* will cancel each other. This prevents core saturation in the output unit. Furthermore, with balance conditions, no fluctuating audio signal current flows down through the

B+ power line into the output resistance or choke impedance of a "B" eliminator or "B" batteries. This reduces the possibility of instability due to feed-back from the power tubes to the detector or first audio tube, and also reduces the possibility of "motorboating."

Since the signal potentials on the grids of the two tubes are 180 degrees out of phase (one is always positive or negative with respect to the other), the fundamental plate currents in the two plate circuits differ by 180 degrees, as shown by the arrows with solid lines in Fig. 182C and the dotted curves "E F" and "J K" in Fig. 182B-A and B. Curve "E F" is the fundamental wave in tube "A" and "G H" is the harmonic. These two combined together give the distorted wave form "C D." Curve "J K" in Fig. 182BB is the fundamental wave in tube "B" and "G H" is the harmonic. These two combined together give the distorted wave from "L M" from tube "B." The harmonics are in phase as shown by dotted curves "G H" in both figures. These undesirable harmonics also happen to be represented by the arrows with dotted lines in Fig. 182C for the instant considered. It will be evident by referring to these current directions at any instant, that in the output unit (whether it be a choke coil or a transformer) the fundamentals (which are 180 degrees out of phase with each other in the tubes) add together, since an increasing current through the upper half of the winding produces the same effect as a decreasing current in the lower half and vice versa. For the same reason, the harmonics (which are in phase with each other) neutralize each other in the output unit and the resultant output to the loud speaker is an amplified reproduction of the fundamental wave only. It is evident from the foregoing that true push-pull action can only be obtained when the two tubes have identically the same characteristics (matched tubes), and the input and output units have accurately located center taps.

The output unit in a push-pull amplifier may be either a choke coil as in Fig. 182C or a transformer as in Fig. 262. When a choke coil is used, if well matched tubes are employed (passing the same plate current), the ends of the winding E and F are substantially at the same D. C. potential, for there will be the same potential drop from the common center tap to E and to F. For this reason the speaker can be connected across these points without danger of any damaging direct current flowing through its windings. This eliminates the necessity for any blocking condensers between the choke and the speaker. However, fixed condensers C1 and C2 of two to four mfd. capacity are sometimes connected in the speaker circuit in order to insulate the speaker terminals from the high plate voltage to prevent severe shock if they are touched by a person whose body is grounded. This is especially advisable when the larger power tubes such as the 210 or 250 types are employed, as the plate voltages used with these tubes are above 300 volts.

Some push-pull output impedances are made with taps placed equally distant from the center tap. These taps are used for the speaker connection when a step-down radio is required for the best operation of low-impedance speakers.

The use of an output transformer with push-pull amplifiers is becoming increasingly popular because it is possible to obtain a better impedance match between the tubes and the speaker by proper design. This is very important when using low-impedance speakers, especially dynamic speakers. The secondary can be

provided with taps for obtaining the best impedance match with any particular speaker. The photograph in Fig. 183 shows a complete audio amplifier unit with first stage resistance coupled, followed by a push-pull output stage. The secondary winding of the output transformer in this unit is tapped to provide output impedance of 1500, 2500 and 4000 ohms respectively. This amplifier may thus be matched effectively to almost any speaker or combination of speakers. A transformer of this type is also shown in Fig. 262.

If the tubes in a push-pull amplifier are matched, and the center taps placed correctly on the input transformer and output device, there are no audio currents in the "C" minus or "B" minus leads, and consequently any electrical disturbance in the filament circuit (such as A. C. current) does not enter into the amplification process. This makes alternating current operation of the filaments without hum easy. This will probably be better appreciated and understood after studying the chapters on A. C. tubes and A. C. tube electric receivers.

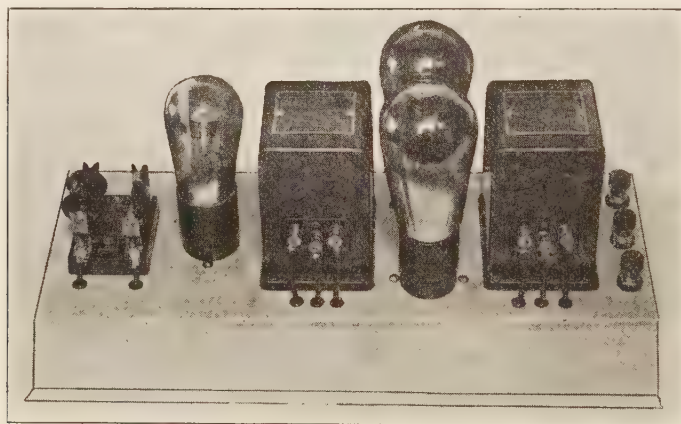


Photo Courtesy Pilot Radio & Tube Corp.

Fig. 183—2 Stage Audio Amplifier With Push-Pull Output Stage

If the tubes in a push-pull amplifier are not even nearly matched, or the transformer center taps are not located correctly, the audio voice currents do not neutralize each other in the "B" minus and "C" minus circuits and the filament circuit are no longer isolated, thus allowing feed-back through the inter-electrode capacity of the tubes to occur. This condition manifests itself usually as a strong amplification of the higher audio frequencies, and if the unbalanced condition is great, the audio tubes will oscillate, producing a steady howl or a high-pitched whistle. Oscillation in push-pull amplifiers can generally be readily prevented by connecting a choke coil (such as the primary of an old audio transformer) or a resistance of about 50,000 ohms in the grid return circuit immediately after the center tap connection of the input transformer. This point is marked "X" in Fig. 182C. No by-pass condenser should be placed across it. This is really a grid suppressor method similar to the grid suppressor scheme used on R. F. amplifiers.

The use of this choke or resistance will not affect the quality, as this circuit does not have to carry any audio frequency currents. Connecting a regular 30 henry choke in the B+ lead from the center tap of the output unit to the "B"+ terminal of the plate supply will also aid in suppressing oscillation, and stopping the whistle.

A push-pull amplifier can be tested for oscillation either by listening for the howl or whistle, or by connecting a low reading milliammeter in the C minus leg at point X in Fig. 182C in order to determine whether any current is flowing in the grid circuit. Under normal conditions there should be no deflection of the needle. However, if the circuit is oscillating, several milliamperes of current may be found to flow in the grid circuit. Then the remedy described above should be applied.

A rough test to determine whether both tubes in a push-pull amplifier are operating properly can be made by operating the set loudly with both push-pull tubes in their sockets, and then removing one of the tubes. If the quality of reproduction becomes poor it indicates that the tube taken out is at least fairly good. If no change is noticeable in the reproduction it indicates that the tubes are not matched. A new tube should then be tried. Now replace this tube and remove the other tube from its socket for the same test. In A. C. tube electric receivers the tubes should only be removed from the sockets for a few seconds, to avoid damaging the remaining tube due to the decreased "C" bias voltage caused by the lowered plate current flowing through the "C" bias resistor, when only one tube is in the socket.

It is evident from this that the answer to the question of whether to use push-pull amplification in a particular set, and just what tubes to employ in the power stage, depends on several factors. Push-pull amplification is not a cure-all for all set ills. It has definite limits and purposes.

First of all it should be remembered that while a properly operated push-pull stage eliminates the harmonics produced in that stage, it does not eliminate the harmonics or distortion produced in other stages. Thus in a two stage audio amplifier with a single tube for the first stage and a push-pull output stage, the push-pull output stage does not correct any distortion appearing in the previous stages. However, the harmonic distortion produced in a high quality first stage (provided the tube is not overloaded) is so small as to be negligible in its effects on the final output.

It must also be remembered that since the plate circuits of the two push-pull tubes are in parallel, the total plate current drain is double that taken by each tube. This factor is sometimes overlooked and the "B" batteries or "B" socket power device used with a set having a single output tube may be seriously overloaded if push-pull amplification is incorporated in the set. Naturally this would cause trouble. This fact must be considered also when substituting larger size power tubes in a set. For instance, suppose a five tube set using one 171A power tube draws a total plate current of 40 milliamperes. The 171A tube alone takes 20 milliamperes. Now suppose the 171A tube is replaced by a push-pull output stage using 245 tubes. Each 245 tube takes a plate current of 32 milliamperes. Therefore the push-pull output stage requires $32 \times 2 = 64$ milliamperes. The entire set then requires $64 + 20 = 84$ milliamperes. This is more than twice the plate cur-

rent drain the "B" batteries or "B" eliminator was called upon to supply before, and it may exceed its rating. Therefore the current rating of the "B" supply device should be ascertained before adding push-pull amplification to a set which formerly used a single power tube in the output. If it will be exceeded under the new conditions, larger "B" batteries or a "B" battery eliminator with larger rated current output should be employed.

Another point to be remembered is that one of the main advantages of the push-pull connection is the increased power output handling capacity provided by the two tubes, over that provided by a single tube. If a set is to be operated so that the volume required from it under normal requirements will never exceed the undistorted power output rating of the single power output tube, it is needless to change that particular set to use larger power tubes or push-pull amplification. The improvement noticeable after the change will be very slight, and will hardly warrant the expenditure required for the new parts. However, if the single tube were being overloaded, the use of a push-pull stage would greatly improve results, for the undistorted power output handling capacity of two tubes in push-pull is nearly *three times* that of a single tube of the same size.

The speaker in a set should also be considered. It should be able to handle the full output of the push-pull output stage without rattling. Unless it is able to do this, the full possibilities of the set will be reduced by the speaker.

A question which often arises in the mind of the radio novice is just what power tube to use in a set. It is just as foolish to use a power tube five times as large as necessary as it is to use one which will overload on loud signals. The table below gives the undistorted power outputs of various power tubes operated singly at various plate voltages. For two tubes in push-pull the undistorted power output capacity is about three times the values shown here for a single tube.

UNDISTORTED POWER OUTPUT IN MILLIWATTS.

Plate Voltage	112A Tube	171A Tube	245 Tube	210 Tube	250 Tube
90	30	130	...	...	...
135	195	330	...	...	...
180	300	710	750	145	...
250	...	...	1600	340	900
400	...	...	...	950	3250
450	...	...	...	1540	4650

The question of which power tube to use is often determined by the fact that a certain plate voltage is available from a set of batteries or a "B" power device which happens to be on hand and the best power tube to be used in this case must be determined. Thus from the table it can be seen that if a plate voltage of say only 90 volts is available, the 171A should be used. If 250 volts are available, the 245 tube should be used as this has a greater handling capacity at this particular plate voltage than even a 250 tube.

The next question is one of plate voltage and plate current drain. The larger power tubes require high plate voltages and draw heavy plate currents. For undistorted output the 171A tube should be operated with 180 volts on the plate and 245 tube should have 250 volts. The 171A tube requires a 40 volt "C" bias at this plate voltage and the 245 tube requires about 50 volts. Thus if the "B" voltage is supplied by a "B" battery eliminator (see Chap. 18) the total voltage

output of the "B" supply device operating the 171A tube should be $180 + 40$ or 220 volts, while the voltage of that for 245 tubes should be $250 + 50$ or 300 volts.

If a set is employing 171A tubes operated from a "B" eliminator furnishing a maximum of 220 volts, this same eliminator will hardly be entirely satisfactory for operating 245 tubes in push-pull, as its maximum voltage output with the large current drain imposed by the 245 tubes in push-pull will be entirely inadequate for the proper operation of these tubes. Also due to the increased current drain on the eliminator, the filtering action of the chokes will be reduced due to the decrease in effective inductance. This will increase the ripple in the plate current and the hum from the set. The "B" eliminator then, should be designed to furnish the required amount of current at the proper voltage, without overloading (see Chapter 18).

If a new set for use in the average home is being built, or an existing set is to be brought up-to-date, the use of an output stage with two 245 tubes connected in push-pull is recommended, with a power supply unit capable of furnishing the correct voltages for the tubes. Two of these tubes will handle, without distortion, all the power one could possibly desire for a home. Of course for amplifier units required to produce a large amount of volume for auditoriums, halls, etc., larger tubes such as the 250 type should be employed.

The following table contains suggested tube arrangements for handling various power outputs without distortion. This has been arranged with a consideration for cost of parts with tubes, cost of power equipment, etc.

Output Milliwatts	Best Arrangement
500 or less	One 171A at 180 volts.
500 to 1000	171A's in push-pull at 135 volts or one 245 with 200 volts plate.
1000 to 1500	Single 245 at 250 volts.
1500 to 2000	171A's in push-pull at 180 volts.
2000 to 5000	245 tubes in push-pull.
5000 — up	250 tubes in push-pull.

In Fig. 262 (Chapter 19) the connections for a modern two stage transformer coupled audio amplifier designed for A. C. socket power operation, and employing a 227 tube for the first audio stage and two 245 tubes in push-pull for the second stage are shown. The method of obtaining filament current, "C" bias voltages and plate voltages is described in this chapter.

From a consideration of the foregoing facts the advantages of the push-pull connection in audio amplification will become evident. The elimination of second harmonic distortion, the greater permissible signal grid voltage swing and undistorted power output handling capacity provided, as well as the reduction of hum with A. C. operation, are important factors. These features have made this form of amplification very popular for the second stage, especially on powerful receivers which deliver great volume. The effective plate resistance of the push-pull combination is equal to twice that of a single tube. The allowable input signal voltage is twice that for a single tube. The undistorted power handling capacity is nearly three times that of a single tube.

239. PARALLEL OUTPUT TUBES: It is sometimes desirable to operate several tubes in parallel in order to obtain greater power output of an audio amplifier. The circuit for a parallel-tube output stage is shown in Fig. 184. The grid of one tube connects to the grid of the other, the two plates are connected together, and the filaments can also be connected together. Evidently more than two tubes can be connected in this way, but for the purposes of explanation we will consider the two tube connection.

The amplification constant of the combination is equal to the constant of a single tube, if both tubes are similar. If one of the tubes has a high μ and the other a low μ , the resultant amplification of the two is equal to the average of the two μ 's. Thus if the μ of one tube is four and that of the other is seven, the resultant amplification constant is 5.5.

For similar tubes the resultant plate impedance will be equal to half the impedance of a single tube and if unlike tubes are used the impedance can be calculated from the laws governing resistances in parallel. The greatest power output is obtained when the two tubes have identical plate impedances and amplification constants, but a very large fraction of the total power of the two tubes can be obtained even if they differ greatly. From two perfectly matched tubes feeding into a load impedance equal to their combined plate impedance, we can obtain twice as much power as can be obtained from a single tube feeding into a load resistance equal to its plate impedance.

As the impedance of the average loud speaker is low at the low frequencies (average impedance of Western Electric 540 AW is 4000 ohms) parallel output tubes are sometimes resorted to in order to secure a better impedance match between the power output tubes and the loud speaker windings, especially at the low frequencies. This is noticeable by the improved reproduction of the low notes. One drawback to this system is that the input signal voltage applied to the grids is limited to that specified for a single tube. This differs from the push-pull arrangement, where the allowable input signal voltage is double that allowed for a single tube.

It is also possible to connect four or more tubes to form a push-pull parallel tube arrangement, in which there are two or more tubes in parallel on each side of the push-pull arrangement. This arrangement secures the benefits of lowered plate impedance and retains the advantage of greater allowable input signal voltage and elimination of tube distortion which is characteristic of the push-pull connection.

240. PHONOGRAPH AMPLIFIERS AND PICKUPS: The electrical reproduction of phonograph records by using the audio amplifier and loud speaker of a radio receiver, or a separate amplifier intended for the particular purpose, has become very popular. The reproduction possible with good apparatus is truly remarkable.

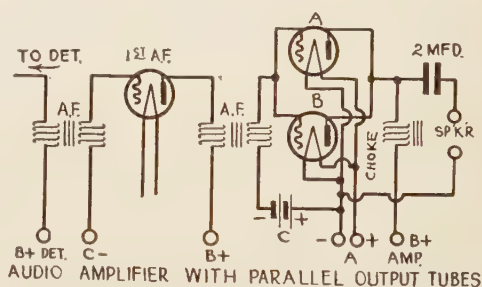
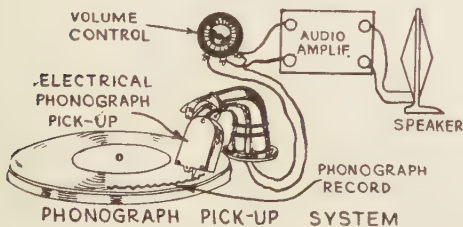


Fig. 184

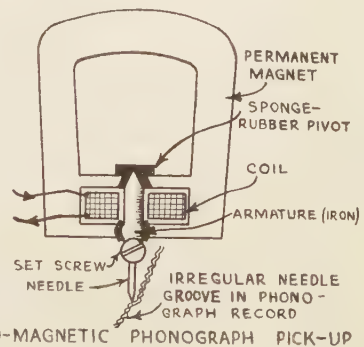
The grooves in a lateral cut type phonograph record are so cut as to cause the needle to vibrate from side to side. In the old type of phonograph, these transverse movements of the needle were conveyed mechanically by a system of multiplying levers to a mica diaphragm located at the small end of a horn. The vibration of the needle caused corresponding vibrations of the diaphragm which set the air column in the horn moving and thus produced sound. This system resulted in considerable distortion due to resonance in the diaphragm and in the horn, and its frequency range was limited.

In the electrical system, the vibratory motion of the needle traveling over the surface of the record is utilized to generate varying voltages in an electric circuit. These variations in voltage represent the vibrations of the needle which in turn represent the sound originally impressed on the phonograph record. The minute electric voltages are amplified by a high quality audio frequency amplifier, such as is a component part of the better radio sets, and then converted into sound by a loud speaker. A simplified sketch of the system is shown in Fig. 185.

241. HOW PICK-UP WORKS: Almost any of the devices commonly used for transforming sound into electrical energy, such as the condenser or carbon microphones, or magnetic transmitters, can be used as phonograph pick-ups, the actuating force being derived from the irregular groove or "track" instead of from a sound wave in the air. The most practical commercial form has been found to be the electro-magnetic type. Fig. 186 shows a simple diagram of one form which is in general use. This is similar in construction to the balanced armature type of speaker unit. A strong magnetic field is provided by a permanent horseshoe magnetic. In the field of this is a small coil of many turns of fine insulated wire. Attached to the needle running in the record groove is a small iron reed or arma-



Above: Fig. 185



Right: Fig. 186

ture which is pivoted, and placed within the hollow center of the coil. As the needle is displaced sideways the direction of the magnetic lines of force in the middle arm of the magnetic circuit (the armature) is reversed, thereby setting up induced voltages in the coil. These voltages vary in proportion to the vibration of the needle and armature. Two wires from the coil are led out for connection to input of the amplifier. In one type of pick-up (Fig. 187) the weight of the pick-up is counterbalanced at the end of the arm, so it does not press down too heavily on the record and cause excessive wear of the record and needle. How-

ever, if the pick-up is made too light it will tend to jump the grooves. The frequency range of the better class of pick-up is from about 60 to 8000 cycles with a practically flat curve. This is ample for reproducing all the notes recorded on phonograph records.

The weak voltages generated in the coil can be applied to the grid or input circuit of an audio frequency amplifier and amplified greatly before going to the

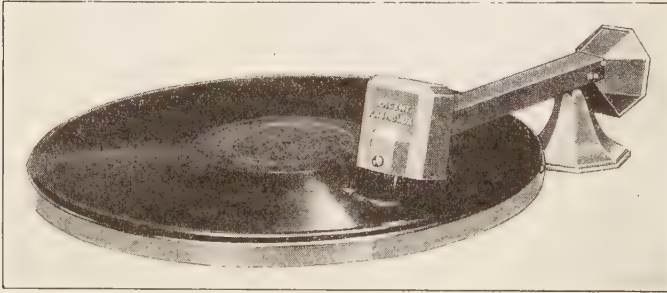


Photo Courtesy Pacent Elec. Co.
Fig. 187—Phonograph Pickup Unit With Counter-balanced Arm

loud speaker as shown in Fig. 188. A two stage amplifier will bring the output of most pick-ups up to loud speaker volume. An ordinary earphone receiver with a needle soldered to the diaphragm will reproduce sound from a phonograph record, but of course the reproduction is not per-

fect, and if the unit is too heavy it will cause excessive scratching and wear on the records.

242. **VOLUME CONTROL:** The volume from a pick-up unit can be controlled smoothly by means of a 50,000 ohm potentiometer (non-inductive) connected as shown in Fig. 188. This keeps the high resistance connected permanently across the pick-up winding so as to prevent change in frequency response. Most commercial phonograph pick-up units are provided with a volume control built into the base, or connected externally in the output leads.

243. **SCRATCH FILTER:** The noise made by the needle as it rides along in the groove is also amplified and makes its appearance in most units as a scratchy noise in the reproduced program. It happens that most of the scratch noises have a frequency of around 4,000 cycles and higher so that they can be by-passed effectively by a series wave trap designed to be tuned to about this frequency.

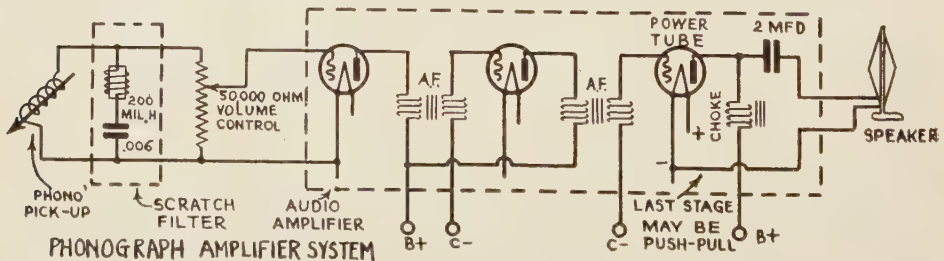


Fig. 188

The connections and constants of the coil and condenser comprising this trap are shown in Fig. 188. Many of the latest pick-up units are designed to eliminate the

needle scratch by lessening the natural period of mechanical resonance of the armature system. No scratch filter is necessary in these.

244. **CONNECTION TO RECEIVER:** If the phonograph pick-up is to be used with the radio receiver in the home it can be connected in several ways, as shown in Fig. 189. In Fig. 189A a double circuit phone jack is wired into the detector plate circuit of the receiver as shown. The pick-up is plugged into this jack and feeds into the primary of the first A. F. transformer in the set. Fig. 189B shows how this can be done with a single pole double throw jack switch.

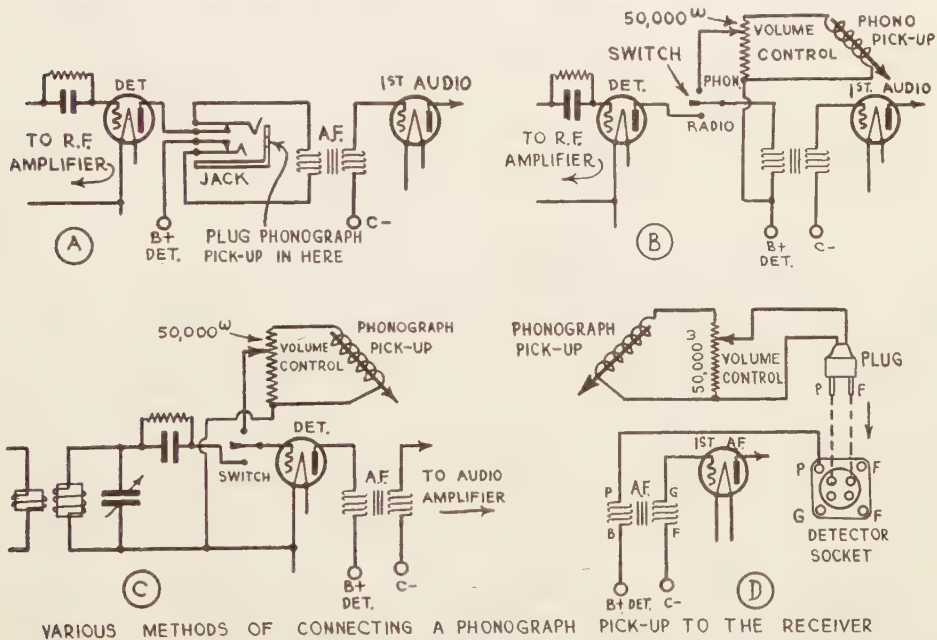


Fig. 189

One side of the pick-up is permanently connected to the B+ side of the audio transformer. In Fig. 189C the pick-up is connected to the input of the detector tube by the switch as shown. As the grid leak and condenser is put out of the circuit, the detector tube acts as an amplifier when the pick-up is connected in. Thus the additional amplification of the detector tube is made use of in this connection. The grid condenser acts as a blocking agent to prevent short circuit of the pick-up by the detector tuning coil. In each case, no radio programs are received while the phonograph is being played as the R. F. amplifier is automatically disconnected from the audio amplifier. The method of Fig. 189C is usually rather difficult to apply in a set as it usually makes the grid leads long with resulting interaction with other circuits.

Some phonograph pick-up units are provided with an adapter for plugging into the detector tube socket. This adapter has the P and F pins connected to the pick-up and when it is plugged into the detector tube socket, the pick-up becomes connected to the input of the audio amplifier as shown in Fig. 189D.

A few of the better grade pick-ups are provided with an input transformer which is connected between the pick-up and the grid circuit of the first audio tube. The purpose of this transformer is to match the rather low impedance of the coil of the pick-up to the high input impedance of the amplifier tube for maximum voltage transfer. For usual purposes an ordinary audio transformer will serve rather well for this purpose.

245. KIND OF RECORDS TO USE: While this new method of playing the phonograph electrically will work with the old records, the results are not as good as when the new Orthophonic (electrically cut) records are used. In former years, records were made mechanically by a machine which had many defects, and their frequency range was very limited. Thus many of the musical instruments in an orchestra were never heard at all because they were not recorded on the record (see Fig. 4 of Chap. 1). Now the records are cut by an electrical recorder which is very much more efficient, and produces records which are far superior both in accuracy in cutting of the groove and wider frequency response limits. Practically the entire useful frequency range of musical instruments is recorded, and orchestras may be heard in their entirety.

246. PHONOGRAPH REPRODUCING OUTFITS: Splendid phonograph reproducing outfits can be made from the small cheap portable phonographs which are commonly used. These have a very satisfactory spring operating mechanism, and with an electric pick-up one may be made into a high quality unit. These portable machines will take full-size records. If desired the mechanism may be removed from the case and mounted in another cabinet, possibly together with the family radio set.

For those people who already have a phonograph of the older type, the addition of a phonograph pick-up feeding into the audio amplifier of the home set will result in many happy hours of enjoyment of good music. Of course, the newer type of "electrically cut" records must be used. The regular tone arm and head on the phonograph should not be used at all.

REVIEW QUESTIONS

1. What is audio frequency? What is A. F. amplification? Why is it used?
2. What are the practical advantages and disadvantages of R. F. amplification; of A. F. amplification?
3. What frequency range is desired in practical A. F. amplification?
4. Explain the cutting of side bands, and how its effects may be partially corrected by proper design of the A. F. amplifier.
4. What three methods of coupling are used in A. F. amplifiers?
6. Explain the action of the audio transformer in an A. F. amplifier stage. Why is it desirable to have a high primary impedance and a low distributed capacity?
7. Draw a frequency response curve for an A. F. amplifier having desirable characteristics.

8. Explain why an A. F. amplifying stage employing a transformer of low turns ratio may sometimes produce more amplification than one using a transformer of high turns ratio.
9. Explain the advantages of shunt feed plate supply.
10. Explain the operation and advantages of the Clough system of shunt plate feed.
11. Explain how distortion may be produced in an A. F. amplifier tube by incorrect "C" bias.
12. Why are power tubes used in the last stage of A. F. amplifiers?
13. Describe the principle of operation and the need for A. F. output filters. Draw a diagram of a satisfactory one consisting of a choke coil and condenser. Why should the speaker circuit be returned directly to the filament circuit?
14. Explain how tube distortion may be detected in a receiver.
15. Describe the advantages and disadvantages of several volume control schemes.
16. Explain the action of the resistance coupled A. F. amplifier.
17. Explain the causes and cures for motorboating in an A. F. amplifier.
18. Explain the operation of the impedance coupled A. F. amplifier.
19. Explain the operation of the autoformer impedance coupled A. F. amplifier.
20. Explain the action of the push-pull amplifier. What are the advantages of the push-pull connection?
21. Explain the action of the parallel tube amplifier stage. What are its advantages?
22. Explain the operation and construction of the phonograph pick-up unit. How does this work with the audio amplifier?
23. What is a "scratch filter" and what is it used for?
24. What is the difference between the electrically cut phonograph records and the old type of mechanically cut records?

CHAPTER 16.

LOUD SPEAKERS

USE OF LOUD SPEAKER—PRINCIPLE OF OPERATION—CLASSIFICATION OF SPEAKER MOTORS—IRON DIAPHRAGM UNIT—BALANCED ARMATURE UNIT—MOVING COIL UNIT—FIELD CURRENT SUPPLY—MOVING COIL IMPEDANCE—COUPLING TRANSFORMER—INDUCTOR DYNAMIC—TYPES OF LOUD SPEAKERS—HORN SPEAKERS—EXPONENTIAL HORNS—CUT-OFF FREQUENCY—DESIGN AND SHAPE OF AN EXPONENTIAL HORN—CONE SPEAKER—FREE-EDGE CONE—BAFFLES—AEROPLANE CLOTH SPEAKER—CONDENSER-TYPE SPEAKER—THEORY AND PRACTICAL FORM OF CONDENSER SPEAKER—LOUD SPEAKER RESULTS—DESIRABLE CHARACTERISTICS—COMBINING CHARACTERISTICS

247. USE OF LOUD SPEAKER: While early radio enthusiasts were content to hear radio programs through earphones clamped tight to their ears, modern standards of reception demand that the sound be reproduced with sufficient volume to be easily heard and distinguished anywhere in at least an ordinary sized room. In some cases, as in large halls, auditoriums, etc., the volume of the sound must be tremendous in order to be heard by large assembled audiences.

The radio receiver amplifies and detects the weak modulated radio frequency signal voltages set up in the antenna circuit, and the function of the loud speaker is to convert the amplified audio frequency currents existing in the output circuit of the audio amplifier into sound waves which are as nearly a true reproduction as possible of the original sound waves in the broadcast studio. The fundamental duty of the loud speaker then is to change varying electric currents into sound waves. The efficiency with which most commercial speakers accomplish this is very low. Many of the poorer grade speakers have efficiencies of around one per cent. Present day loud speakers are by no means perfect, but are capable of very good results.

248. PRINCIPLE OF OPERATION: Telephone receivers and loud speakers have been designed to operate on a number of basically different principles. The reaction between a coil and eddy currents set up in a disc; the electrostatic attraction or repulsion between two charged metal plates; thermal expansion and contraction of a wire with variation of current through the wire; the "talking" arc; the expansion and contraction of crystals under the influence of an alternating electric field; all these and many other schemes have been used with more or less success. Practically all commercial speakers in use now depend upon the variation in the pull of a fixed magnet (permanent or electromagnet type) on an iron bar, armature, iron diaphragm or a coil carrying a current. The essential parts of a speaker operating on this principle (no matter of what type) is a constant mag-

netic field upon which acts a second magnetic field which varies in accordance with the audio frequency current, thereby causing motion of the armature, the diaphragm or the moving coil in accordance with the variations in the audio frequency current. Electrostatic speakers are rapidly being developed to a state of commercial perfection.

249. **CLASSIFICATION OF LOUD SPEAKER MOTORS:** The part of the loud speaker which changes the varying audio frequency currents into mechanical vibrations is called the "motor" or "driving unit". Loud speaker units may be divided into several classes. The first refers to the method of exciting the constant field. Those which use a permanent magnet belong to the magnetic type. Those in which the strong constant magnetic field is produced by a current-carrying coil wound on a core of steel are called electromagnetic (commonly called "dynamic" speaker).

A second classification divides speaker "motors" or "units" into iron diaphragm, balanced armature, and moving coil types.

250. **IRON DIAPHRAGM UNIT:** The iron diaphragm type of unit has the same general construction as the ordinary watch-case receiver described in Chapter 4. As shown in Fig. 190, this consists of a permanent magnet with

coils of fine wire wound over the pole pieces. The diaphragm is placed over the poles of the magnet and separated from them by only a small fraction of an inch. The coils are connected in series with the circuit in which the pulsating direct current is flowing, and the magnetic field produced by this current varies the total magnetic field of the magnet, causing the attraction for the iron diaphragm to vary, making it vibrate. The vibrations of the diaphragm correspond to the frequency of the pulsating current and therefore the pitch of the desired music is reproduced. Also, as the current varies in intensity with the loudness of the sound, the amplitude

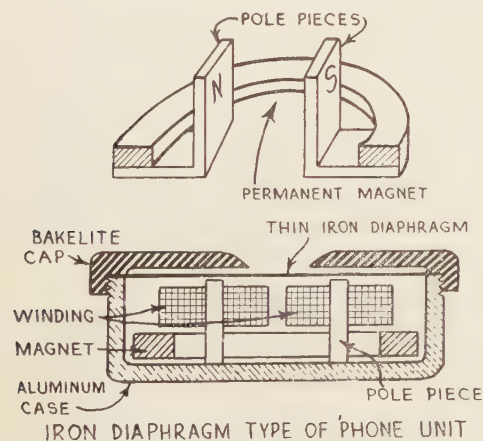


Fig. 190

of the vibrations of the diaphragm will increase in the same proportion. The vibrating diaphragm sets up vibrations of the air with which it is in contact, producing sound waves.

A serious objection to this type of unit is that the diaphragm is under stress and is deflected by the magnetic field of the permanent magnet even when no signal is being received. (See Fig. 27, chapter 4.) This limits the amount of vibration possible without rattling by striking against the pole pieces, when a strong signal is being received. Thus if a unit of this type is to be sensitive, the air gap between the diaphragm and the pole pieces must be kept small. This reduces the working amplitude of vibration possible without striking the pole pieces, and makes the unit unsuited for large volume. If the air gap is made

large to permit of the large amplitudes of vibration necessary for large volume, the unit is not sensitive on weak signals. Also the diaphragm, being of iron, is comparatively stiff. This makes it difficult to build a unit of this type having good frequency response. The diaphragm usually resonates at certain frequencies, causing abnormal response to notes of these frequencies. This type of unit is no longer used much in loud speakers.

751. BALANCED ARMATURE UNIT: The balanced armature unit, Fig. 191, is an improvement over the iron diaphragm type as it gives very good response to weak signals and can be built so it does not chatter easily when handling strong signals. The initial pull or deflection of the diaphragm of the iron diaphragm type is done away with by a construction which balances the initial pull of one set of poles against the other.

Fig. 191 shows a balanced armature type driving unit connected to the output circuit of a power tube with output filter. The unit is operating the diaphragm in the throat of a horn speaker. A short soft iron bar or armature A, which acts as the core of a coil of several thousand turns of fine wire (or two coils in series) carrying the audio frequency current, is pivoted at its center and is free to move in a small arc about this center pivot point. Each end of the armature is near one of the pole pieces of a strong permanent horse-shoe magnet M. Enough clearance is provided between the armature and the inside of the coil, so the motion of the armature is not restricted.

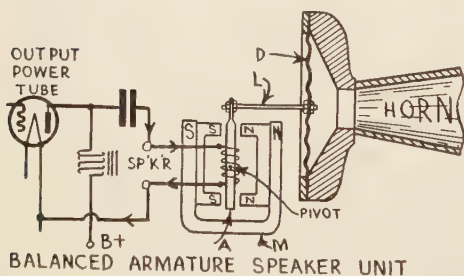
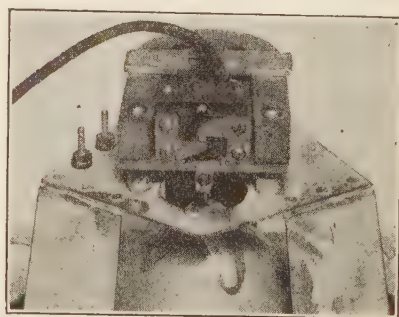


Fig. 191



Balanced Armature Cone Speaker Unit

Fig. 192

When a signal current flows through the coil, a magnetic field is produced, which magnetizes the soft iron armature. The poles react on the poles of the permanent magnet and attraction between the unlike poles and repulsion between the like poles takes place. With the polarities shown in Fig. 191, the top end of the signal current flows through the coil in the direction shown by the arrows. The amount of pull or movement is proportional to the current flowing through the coil, so the armature moves in accordance with the variations in the current. The armature imparts its motion to the center of a non-magnetic diaphragm of thin mica or aluminum through a simple rod L, or in some cases through a more or less complicated system of levers. As equal pulls are produced at

each end of the armature, the motion is balanced. The amplitude of vibration of the diaphragm may be increased and the pushing force decreased, or the motion may be decreased and the pushing force increased by the mechanical lever action of the link. The pivot point of the armature is the fulcrum. Units of this type made for use with long horns usually have a wide flat, thin armature, to secure a great driving force. The photograph of Fig. 192 shows a very popular unit of this type which is used to drive cone speakers.

252. USES AND FAULTS OF BALANCED ARMATURE UNIT: The balanced armature type of unit is used extensively for driving the diaphragms in horn speakers, and driving the paper cones of cone speakers. This unit has been brought to a high degree of perfection and can be made to give splendid performance by proper use. It was the most popular type of unit for several years and is only recently giving way to the "dynamic" type of speaker unit. One disadvantage of this type is that for good sensitivity the air gap between armature and pole pieces must be made very small to reduce the reluctance of the magnetic circuit and obtain a strong magnetic field. This is objectionable when receiving loud low notes, since the movement of the armature may be so great that its sides strike the pole pieces, causing a rattling sound. If the air gap is made large in order to provide for greater amplitude of vibration, and the sensitivity is increased by greatly increasing the number of turns of the coils, the high frequencies will not be reproduced, due to the increased distributed capacity of the coils causing a by-passing effect to the currents of these frequencies. However, for moderate amounts of volume, this type of unit is perhaps the best we have at present, especially when the cost is considered as a factor.



Courtesy Racon Elect. Co.

**Fig. 192-A—Moving
Coil Unit for Use
With Horn**

253. MOVING COIL SPEAKER UNIT: In the moving coil type of speaker unit, a very small, exceedingly light cylindrical coil of wire carrying the audio current, moves back and forth in the annular magnetic field between two concentric strong magnetic poles. The coil is attached (usually directly) to a paper cone, or a non-magnetic diaphragm when used with a horn. A moving coil speaker unit with diaphragm for use with horns is shown in Fig. 192.

254. DYNAMIC SPEAKER UNIT: The most popular form of moving coil speaker employs a very strong electromagnet (instead of a permanent magnet) for producing the steady magnetic field and is commonly known as a "dynamic" speaker unit. It is unfortunate that this name has come into common usage for properly speaking, all forms of speaker units are "dynamic" speakers since the motion is caused by a force.

A more appropriate name would be electro-dynamic speaker, since the force and motion is produced by the action of two electric currents (the varying audio currents and the steady field current).

255. OPERATION OF DYNAMIC SPEAKER UNIT: Fig. 193 shows a cross sectional view of an electro-dynamic speaker unit connected to the output

circuit of a power tube, and used to drive a free-edge cone. The powerful steady magnetic field (about 12,000 lines per sq. cm.) is produced by the electromagnet winding "E," wound on a soft steel core. A powerful radial magnetic field exists in the air gap between the center core and the outside part of the core which also forms a protective housing. The audio currents from the radio receiver flow through the light movable coil B of between 100 and 150 turns of fine wire wound on a thin cylindrical shell of Bakelite and mounted in the annular space between the poles with as small a clearance as is mechanically practicable. The interaction of the powerful steady field of coil E, with the varying field produced by the audio signal current in coil B, produces motion of coil B along the line of its axis. Coil B can be directly connected to a cone or diaphragm for setting the air in vibration to produce sound waves.

As the movement is along the axis line of the coil, the air gap between the pole pieces can be made very small (usually about 0.005 inch) without danger of the coil striking the pole pieces. Hence it can be made to produce large amplitudes of vibration without rattling, with resulting great volume.

256. FIELD CURRENT SUPPLY: The field winding E must be excited by an external source of direct current. Some models have fields designed to be excited from a six volt storage battery (take about 0.75 ampere). More recent models use 110 volts alternating current from the electric light lines, and include a rectifier unit (Fig. 193) for changing the A.C. line current to direct current for the winding.

Some electric sets use the field or "pot" as one of the choke coils in the filter circuit of the B— eliminator. The steady direct B current of the eliminator flowing through this field coil, energizes it, as shown in Fig. 193A. Since the field consists of a large number of turns of wire wound on a magnetic core it has quite a large inductance and acts as a choke coil. This can only be done practically on power packs where the voltage is from 100 to 200 volts, by supplying a pot field of proper resistance. The voltage drop across the pot field will be around 100 volts and at this voltage the current will

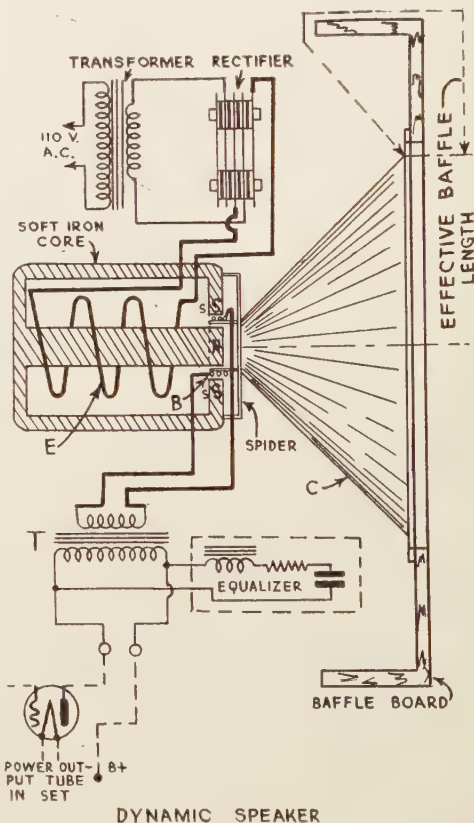
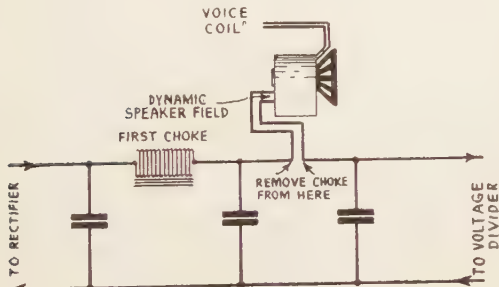


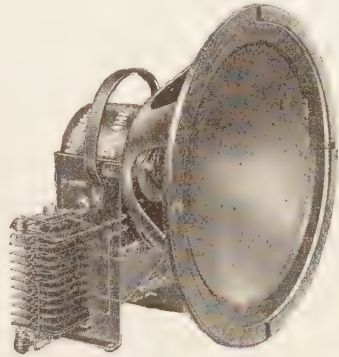
Fig. 193

be 40 milliamperes if the field coil has a resistance of 2500 ohms. All of the current which the B power pack is delivering must flow through this field. Unless about 40 milliamperes or more are being delivered by the power pack, the field of the average speaker will not be excited fully. Of course radio set manufacturers can design the fields of their speakers to suit the conditions to be met with in their particular "B" power unit. This method of excitation saves the expense of one choke coil in the "B" eliminator, and also saves the expense of a rectifier and step-down transformer in the loud speaker, and is extensively used by set manufacturers. Other models have fields wound to



CONNECTION OF A DYNAMIC SPEAKER FIELD FOR USE AS A FILTER CHOK IN A B ELIMINATOR.

Fig 193A



Courtesy The Magnavox Co.

Fig. 194
Dynamic Speaker With Dry
Plate Rectifier

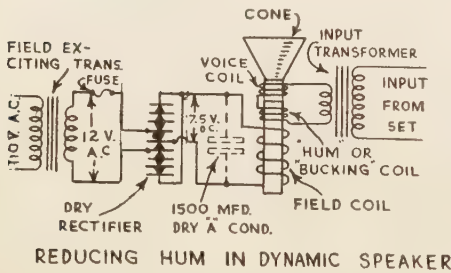
take their current directly from 110 volt direct current electric light supply lines, where this current is available.

Among the types utilizing the 110 volt A.C. for field current supply, two types of rectifiers are in use. In one popular form the 110 volt A.C. is stepped down to about 6 to 15 volts and about $\frac{1}{2}$ ampere by a transformer, and rectified by a contact-type of dry plate rectifier, without any filtering. The connections for a unit of this type are shown in Fig. 193, and Fig. 194 shows the actual speaker. The current supplied by a rectifier of this type (as will be explained in Chap. 18) is a pulsating direct current. It is evident that the magnetic field produced by this current will also fluctuate. Since the moving coil is in the field of this flux, there will be a reaction between it and the varying magnetic flux and the coil will tend to move and its movements will have the same frequency as that of the field current. If the diaphragm or cone moves, sound is produced and an audible hum results. The effect of this pulsating field current can be reduced greatly by a small fixed "bucking" or "hum neutralizing" coil which is wound around the pole piece of the electro-magnet (see Fig. 195) and near the moving coil. It is connected in series with the moving coil and the secondary of the coupling transformer. As the bucking coil is also in the magnetic field it has induced in it a voltage corre-

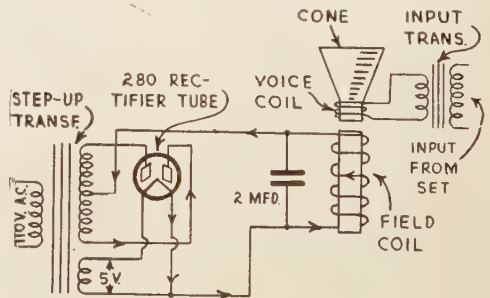
sponding in frequency to that of the pulsating field current. By making the bucking coil of the proper number of turns, and connecting it in the proper direction, its induced voltage can be made equal and opposite to that produced directly on the moving coil by the flux. Therefore, the two effects balance each other and the hum is prevented—or at least greatly reduced.

One disadvantage of the bucking coil is that it also tends to reduce signals around the hum frequency of 60 and 120 cycles and therefore results in slightly lowered low-frequency response.

Obviously the bucking coil method of hum reduction is only practical when the coil can be included in the speaker at the time of manufacture. A very effective way of eliminating hum in existing dynamic speakers which use the low voltage type of dry rectifier is shown in Fig. 195. A dry A-filter



Left: Fig. 195



Right: Fig. 196

condenser of from 1500 to 2000 mfd. capacity is connected across the field coil. This large capacity serves to filter or smooth out all ripples in the field current. It should be remembered, however, that these condensers can only be used on speakers in which the low voltage (about 15 volts) type of dry rectifier is used, as the condensers have a very low breakdown voltage. In connecting the dry "A" condenser across the circuit it is important to make sure that the negative (black) lead of the condenser is connected to the negative side of the circuit, and that the positive (red) lead of the condenser is connected to the positive side of the circuit. The polarity of the circuit should first be determined with a voltmeter.

In another type of electro-dynamic speaker for use on 110 volt A.C., a high-voltage low-current field winding is used. Power for the field is supplied by a full-wave rectifier tube (UX280) which operates in connection with a full-wave transformer having a five volt filament winding and two 200 volt secondaries to deliver about 180 volts D.C. to the speaker field. The connection of the rectifier tube shown in Fig. 196 is similar to that in Fig. 241. This current is filtered or smoothed out by one or more 2 mfd. filter condensers in combination with the choking action of the high inductance field coil itself,

so as to eliminate any A.C. hum which might be set up in the speaker by fluctuations in field current. This does away with the "bucking" coil with its objectionable features. Also the vacuum tube rectifier used is more reliable in operation than the dry disc type of rectifier and can very easily be replaced by simply plugging a new tube in the socket. Fig. 196 shows the connections for a speaker of this type. The higher voltage used for the field makes filtering easy. The photograph of Fig. 197 shows a complete speaker of this type with the rectifier tube on the right hand side. Notice the sturdy frame supporting the cone, and the ease with which the rectifier tube can be replaced.

257. **MOVING COIL IMPEDANCE:** The moving or "voice" coil of dynamic speakers is usually wound with a few turns (about 100) of fine wire (about No. 34 B. & S.) on a thin cylindrical insulating shell. One very efficient speaker has a moving coil made of several turns of aluminum alloy strip 0.002 inch thick wound edgewise. As the moving coil contains a small number of turns its inductance is small, and it has a low impedance. Also as the inductance is low, the coil offers almost a pure resistance load on the power tube, and the impedance therefore is nearly constant throughout the frequency range. This latter feature is very desirable since it is desired to have the speaker respond alike to all frequencies. In one commercial unit, the impedance is about four ohms at 100 cycles and 20 ohms at 6000 cycles.

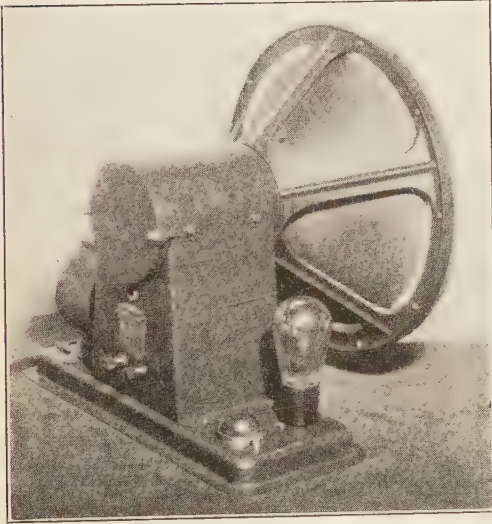


Photo Jensen Radio Mfg. Co.

Fig. 197—Dynamic Speaker With 280 Type Tube Rectifier

As the moving coil must be connected in the output circuit of a single power tube (or two power tubes in push-pull) of a receiver it is desirable that the tube deliver as much undistorted power to the coil as possible. As has been shown previously, a tube delivers the maximum amount of *undistorted* power output when it works into a load resistance equal to twice the plate resistance of the tube. *Maximum power output* however, is obtained when the load resistance equals the tube's plate resistance. However, it is not necessary to match these exactly as quite a large percentage of the maximum undistorted power output can be obtained even though the load resistance is four or five times greater than the plate resistance of the tube. It is bad practice to work a tube into a load resistance which is much less than its own plate resistance. This would be the case if the moving coil of a commercial dynamic speaker were connected directly in the plate circuit of one of the common power tubes, whose plate impedances vary between 2000 ohms for a 171-A tube, 1900 ohms for a 245 tube and 5000 ohms for a 210 tube.

258. **COUPLING TRANSFORMER:** Most dynamic speakers use a special coupling transformer between the power tube and the moving coil to bring these impedances into the proper relationship. This consists, like an audio transformer, of two coils of insulated wire wound on a laminated steel core. It is wound to match the plate impedance of the power tube to the lower impedance of the moving coil. As the impedance of a coil varies as the square of the number of turns, the transformer is designed so that the square of the ratio of secondary turns to primary turns is equal to the ratio of speaker impedance of the desired effective impedance, that is:

$$\left(\frac{T \text{ sec.}}{T \text{ prim.}} \right)^2 = \frac{\text{IMPED. SPK'R.}}{\text{EFFECTIVE IMPED.}}$$

Thus, if the moving coil has an impedance of 10 ohms at some frequencies and it is desired to match it to a 1900 ohm plate circuit of a 245 type power tube, a plate load of twice 1900 or 3800 ohms is required to get maximum undistorted power output. Substituting these values we have

$$\begin{aligned} \left(\frac{T \text{ sec.}}{T \text{ prim.}} \right)^2 &= \frac{10}{3800} \\ \text{or } \frac{T \text{ sec.}}{T \text{ prim.}} &= \sqrt{\frac{10}{3800}} = \sqrt{\frac{1}{380}} = \frac{1}{19.5} \end{aligned}$$

That is, the primary of the coupling transformer should have 19.5 times as many turns as the ~~primary~~ *secondary*. When a push-pull output circuit is used, it must be remembered that the output plate impedance is equal to twice that of one of the tubes. Thus in this problem, if two 245 tubes in push-pull had been specified, the output plate impedance would be two times 1900 or 3800 ohms. The plate load to get maximum undistorted power output would then be 3800 times two or 7600 ohms. For two similar output tubes connected in parallel, the output plate impedance is equal to one-half that of a single tube.

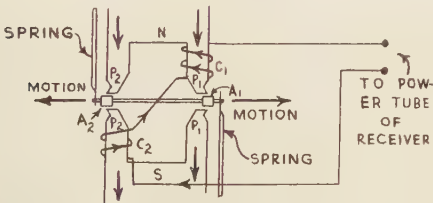
With well designed apparatus, the result is practically the same as if the speaker were suited to the tube. The connection of the coupling transformer "T" is shown in Fig. 193. Notice that it is a step-down transformer. The proper coupling transformer is usually included in the housing of the dynamic speaker, so that when a dynamic speaker is connected to a receiver which has an output transformer or output filter in it, the output transformer or filter should be disconnected from the receiver first, and the dynamic speaker input terminals connected directly in the plate circuit of the power tube. An analysis of the characteristics of the coupling transformer circuit shows that it is not necessary to have the coupling transformer of exactly the correct ratio for satisfactory results. If this were the case, a special coupling transformer would have to be used for each type of power output tube, since nearly all power output tubes have different plate impedances (see Fig.

54). A coupling transformer designed to make a moving coil function satisfactorily with a 5000 ohm tube (type 210 for example) would also be satisfactory for a 2000 ohm tube (such as the 245 type), although a transformer satisfactory for the 2000 ohm tube would not be very satisfactory for use with the 5000 ohm tube. These considerations have caused most loud-speaker manufacturers to design the coupling transformer to give best results from a 5000 ohm tube, knowing that such apparatus will be satisfactory with 2000 ohm tubes. Of course, slightly greater efficiency might be obtained by using the proper transformer in each case. Some manufacturers use a tapped transformer so that proper matching can be obtained with any type of tube for best performance. Because coupling ratios are not critical it is fairly safe to say that any commercial dynamic loudspeaker unit may be satisfactorily connected to the output of almost any receiver. In some cases, however, somewhat more efficient results can be obtained by using a special coupling transformer.

In sets having push-pull output, satisfactory operation will be obtained with most commercial dynamic speakers by connecting them directly to the set output terminals (secondary terminals of push-pull output transformer in set). Some sets use a very special push-pull output transformer having only a few secondary turns matched to operate directly into the voice coil winding of the conventional type of dynamic speaker, omitting the input transformer in the speaker. In this case, the push-pull output transformer secondary should be connected directly to the voice coil only, or else the regular dynamic speaker input terminals should be connected directly to the outer terminals of the primary of the set output transformer, ignoring the secondary terminals of this transformer entirely.

259. INDUCTOR DYNAMIC SPEAKER: The Farrand inductor dynamic speaker unit is one of the most recent types developed. The unit uses two powerful U shaped permanent magnets (see Fig. 201) to supply the fixed magnetic field. Instead of the usual moving coil or armature bar, the armature consists of two separate iron bars connected by tie rods as shown in Fig. 198 and 199, each bar working between its respective pole faces.

The armature has a reciprocating motion instead of a rotary one. The coils P1 and P2 consist of several thousand turns of fine magnet wire



CROSS-SECTION OF THE INDUCTOR
DYNAMIC LOUDSPEAKER UNIT

Fig. 198

wound on bobbins which are slipped over the pole legs. The action is as follows: The armature assembly rides freely between the pole pieces P1 and P2 (Fig. 198). Coils C1 and C2 are connected in series. A signal current flowing through the winding in the direction indicated will increase the flux (magnetic field) through the pole legs P1 and decrease the flux through the pole legs P2 (remembering that the magnetic lines of force of a magnet flow from the north

pole across the air gap to the south pole as shown by the arrows in Fig. 198). The flux, seeking the path of least reluctance exerts a greater force on the armature bar A1 than on bar A2, thus moving the armature to the left. On the reverse of the cycle the armature moves in the opposite direction in the same manner. The pole legs are cut to the shape indicated to reduce the leakage flux and to bring the greatest flux density to the most desired point.

If the inside spacing between the armature bars is equal to the center spacing of the pole faces, the flux in the magnetic circuit P1 A1 P1 varies 180° out of phase with the flux in the circuit P2 A2 P2 as the armature is moved to its two extremes. This would give extreme sensitivity but there would then be no magnetic restoring force. If the armature bars are brought closer together, a distance corresponding to 18 electrical degrees, the resulting sensitivity is slightly decreased but there will be a restoring force set up, which will restore the armature to its initial position. The total flux is greatest when the armature is in its "at rest" position and represents the magnetic restoring force, or, if you will, the "magnetic stiffness." This is the design used in practice.

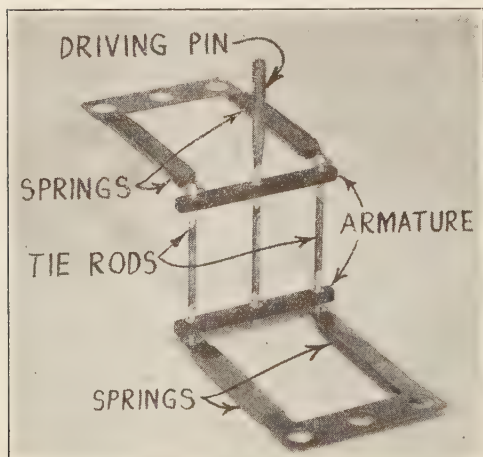
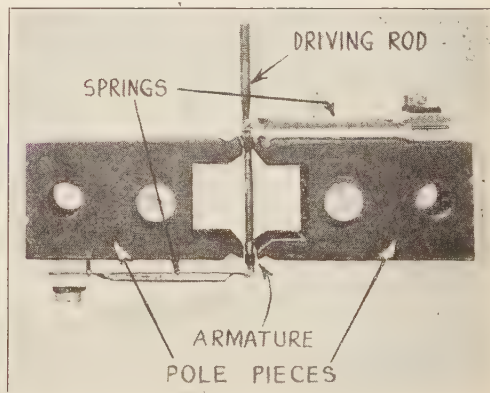


Fig. 199—Armature Assembly of Inductor Dynamic Unit



Photos Courtesy Farrand Elect Co.

Fig. 200—Placement of Armature Between Pole Faces of Magnet

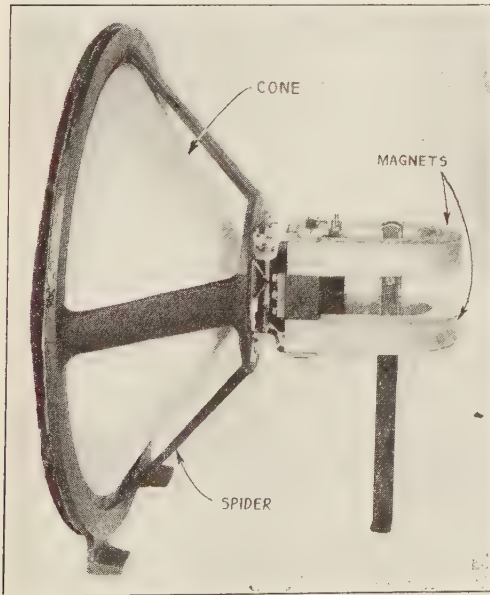
It is evident that any D.C. component of current flowing through the windings would change the position of the armature by moving it to one side or the other, thus reducing its limit of motion in one direction. For this reason there must be no D.C. flowing through the windings, thus making it necessary to use an output transformer or a choke and condenser. However, if the loud speaker is to be used on a push-pull amplifier, a third lead may be taken from the windings at the point where the two coils are connected together and used as the mid-tap of the windings. This corresponds to the mid-tap on

the primary of the usual push-pull output transformer. The D.C. which flows through the windings in this manner does not upset the "magnetic center." On the contrary it should be in such a direction as to aid the permanent flux through the poles. Doing away with the output transformer in this manner does away with its attendant losses and the gain is readily noticed by the ear.

It has been found that matching the impedance of the inductor dynamic to that of the amplifier with which it is to be used is of greater importance than it was with the moving-coil dynamic speaker. The latter may be varied over quite a wide range before the ear will detect any great change in operation. However, this is not the case with the inductor dynamic. If the loud speaker has too high an impedance for that of the amplifier with which it is used, the efficiency is lowered at the higher frequencies and increased at the lower frequencies. Since the loud speakers are made in four different models, each having a different impedance, and distinguished by a different color marking on the chassis, this feature afford the listener the chance to pick a loud speaker which will give the balance of high and low frequencies which is most pleasing to him.

Fig. 200 shows the placement of the armature between the pole faces of the magnet. A complete unit with paper cone and supporting frame is shown in Fig. 201.

The advantages of this type of speaker are that as the armature moves in a line parallel to the pole faces, it can be constructed to be sensitive due to the small air gap, and yet produce large amplitudes of vibration without striking the pole pieces. The armature moves over one-eighth inch when reproducing low notes. Also the use of strong permanent magnets makes the unit cheaper and more simple than the electrodynamic speaker and there is no possibility of objectionable hum being introduced by the speaker, due to the elimination of all electric light power supply, rectifiers, etc.



Photos Courtesy Farrand Elect Co.

Fig. 201—Complete Inductor Dynamic Motor With Cone and Frame

The name inductor-dynamic originates from the fact that the motion as force ("dynamic") is derived from a magnetic induction action ("inductor") similar to that in an A.C. induction motor where a rotor revolves under the influence of a changing magnetic field. Units of this type are usually used to drive 10 or 12 inch paper cones for setting the air in vibration and producing sound waves.

260. **TYPES OF LOUD SPEAKERS:** The application of the various

loud speaker motor or driving units just described will now be considered. Practically all loud speakers (except the electrostatic type) may be roughly divided into two general classes. They are, horn speakers and cone speakers. Although many different mechanical constructions which do not appear to resemble each other are used in loud speakers, a careful inspection of any one will show it to belong to one of these types.

261. HORN SPEAKERS: In the horn type of speaker a small diaphragm driven by any one of the motor units described, is placed at the small end or throat of the horn. The vibration of the diaphragm sets up sound waves which travel out of the mouth or open end of the horn into the open air. The function of the horn is to enable the relatively small diaphragm to get a grip on the air. That is, the horn causes the pressure per square inch over the surface of the diaphragm to be many times greater than if the diaphragm were to vibrate in free space, thus enabling more sound to be radiated from the diaphragm. Of course, it is possible to radiate sound directly from the vibrating member to the air, but much larger surfaces are required when this is done. The horn enables a small diaphragm to radiate large amounts of sound to the atmosphere. The loading effect of the horn can be demonstrated very easily by removing the driving unit and diaphragm from a horn speaker while it is operating. As soon as the loading influence of the horn is removed, the amplitude of vibration of the diaphragm will be so great that it will rattle. Notice also the decrease in volume of sound when the horn is removed. The horn really makes the diaphragm work harder!

262. POSSIBLE SHAPES OF HORNS: Horns can be made in many different shapes and sizes but it has been shown experimentally that certain types of horns are most suitable as they give best results. Straight pipes of uniform diameter are unsuited for loud speaker horns because they are efficient resonators only within certain narrow frequency limits corresponding to the fundamental tone, and may increase the sound energy in these narrow frequency bands thousands of times. Outside of these narrow frequency bands no increase in sound energy is brought about. Horns of various shapes have been designed and any one of these is better than a straight pipe for a loud speaker, because horns have less pronounced resonant properties than pipes.

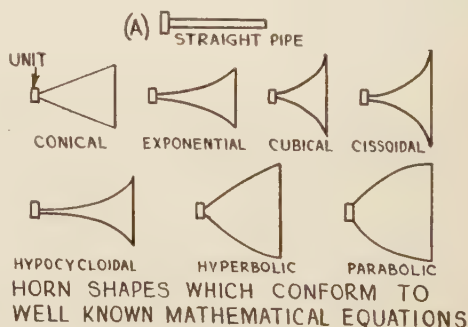


Fig. 202

Fig. 202 shows a straight pipe (A), and horns of various possible shapes following well known mathematical equations. These equations determine the manner in which the cross-sectional area changes as we advance from the small end to the large end of the horn. The result, obtained with these various horns differ greatly. The shape which seems to give the best performance for practical loud speaker work, is the exponential type. Of all horns having a given size

(i. e. same length and terminal areas), the exponentially shaped horn is the most uniform sound radiator over the required range of frequencies.

263. **EXPONENTIAL HORN:** A true "exponential horn" is one whose cross section area doubles at equal intervals along its length or axis. For example, if a horn has a throat with an area of one quarter square inch, and at one, two, and three feet from the throat the section areas are one half square inch, one square inch and two square inches respectively, we have an exponential horn in which the area doubles every foot. A horn whose area doubles at smaller intervals would be said to expand more rapidly, and one whose area doubles at longer intervals would expand at a lower rate. This exponential rate is sometimes called the "law of organic growth," as it is the rate at which most plants, trees, and other organic materials increase in size.

264. **CUT-OFF FREQUENCY:** The radiation of sound from an exponential horn decreases at the low frequencies, and the horn will radiate very little sound or none at all below a certain definite frequency, called the "cut-off" frequency. The cut-off frequency is determined by the rate of expansion of the horn. A horn which doubles in area every two feet will reproduce down to about 32 cycles, one which expands twice as rapidly, i. e. doubles in area every foot will only go down to 64 cycles, etc.

The length of the horn is determined by several factors. First, a properly designed horn should be free from noticeable resonance. To prevent this, the mouth of the horn should be made large enough to transmit the sounds coming from it without any great amount of restriction which would cause back-pressure. It has been found that if the diameter of the mouth is made comparable to one-quarter of the wavelength corresponding to the cut-off frequency of the horn (as determined by its rate of expansion), the resonance in the horn will be negligible. The wavelength of sound in feet is determined by dividing the velocity of sound in feet per second (1120) by the frequency. So the horn should be extended until the mouth has a diameter about one-quarter the wavelength corresponding to the cut-off frequency. If the horn section is approximately square, the area of the mouth should be as large as that of the circle having this diameter. For instance, following out this reasoning a horn whose cut-off frequency is 64 cycles, corresponding to a wavelength of 1120 divided by 64 or 17.5 feet, should have a mouth about 17.5 divided by 4, or 4.4 feet in diameter if circular; or about four feet by four feet if square.

The diameter of the small end or throat of the horn depends on several factors. Since the diaphragm really acts like a piston pumping air in and out of the throat of the horn, if the area of the throat is small, practically all of the air displaced by the diaphragm will move into the horn and only a small part of the motion will be lost in compressing the air in the cavity just above the diaphragm. However, the throat would then be retarded too much by the throttling effect. Also in order to secure a slow rate of expansion with consequent low cut-off frequency, the initial opening should be large. There must, therefore, be a compromise made between these factors in the design of the horn. Most commercial loud speaker driving units of the balanced armature type built for use on exponential horns have an opening about five-eighths of an inch in diameter.

265. **DESIGN OF AN EXPONENTIAL HORN:** Let it be required to design an exponential horn having a cut-off frequency of 32 cycles and to be used with an ordinary balanced armature driving unit having a five-eighths inch diameter opening.

If the cut-off frequency is to be 32 cycles, the exponential horn will double in area every two feet. The cut-off wavelength will be 1120 divided by 32 equals 35 feet. The diameter of the mouth should then be 35 divided by four or about 8.75 feet.

The area of the throat is equal to the square of the diameter times 0.7854, or 0.314 square inches. As the area doubles for every two feet, at a point two feet from the throat the area is $0.314 \times 2 = 0.628$ square inches, at six feet it is $1.356 \times 2 = 2.712$ square inches, etc. This is carried out until such length when the mouth of the horn determined by the cut-off frequency is reached. The figure for the mouth of the horn opening must be converted into area. Actually the length of this horn would have to be about 28.5 feet. It is evident that such a "true exponential horn" would be large and unwieldy for home use. In practice, so-called exponential horns built for home use are not true exponential horns but are about seven or ten percent exponential. That is each succeeding area is not double that of the previous section but is about seven percent of this double value. The results obtained with these horns are not as good as with true exponential horns, but the sacrifice in operating quality must be made on account of the allowable size of a practical horn for home use. Fig. 291A shows a large type of exponential horn made by the Racon Electric Company and used for theatre work in connection with the "talkies". This horn has an air column of ten feet, and a bell 40 by 40 inches. As it weighs about 45 lbs. it is supported on a wooden framework. A dynamic horn speaker unit of the type shown in Fig. 192A is used with it.

266. **MATERIAL AND SHAPE OF HORN:** The material of which



STRAIGHT, COILED, AND FOLDED EXPONENTIAL HORNS

Fig. 203

the horn is made is important. Although a horn may be well designed and constructed to correct size, total length, rate of expansion, etc., it may still fail to

give good results because of resonant effects in the material used in the construction. The material used should have no marked resonant frequency, unless this resonant frequency is very low. One manufacturer uses a special construction of fleeced underwear cloth moulded together to correct shape and impregnated by a special binder compound. Another uses a special composition consisting of wood sawdust held by a binding compound and moulded to correct shape.

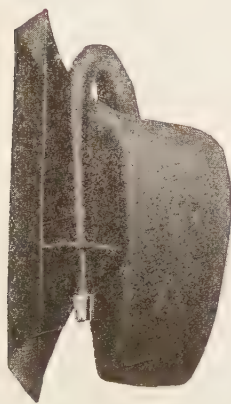


Fig. 204—Coiled 104 in. Exponential Speaker for Home Use

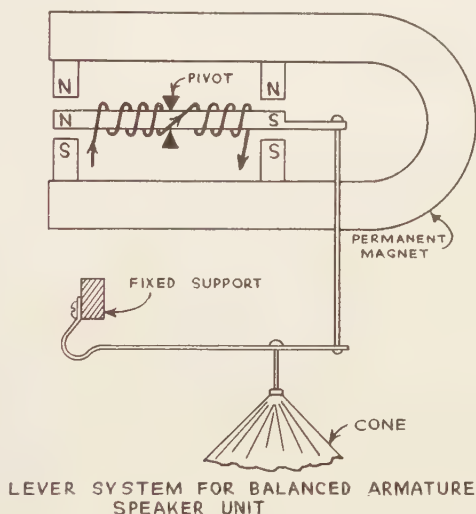


Fig. 205

It is evident from the foregoing calculations that the old type of short horns one or two feet in length cannot possibly reproduce the low notes. The best they can do is reproduce the higher harmonics of these notes, and the ear responding to these makes it appear as though some of the low notes were being heard. Exponential horns which do reproduce the low notes must necessarily be long. In order to put these speakers in the small spaces available in the home, they are usually made of coiled or folded up construction. Fig. 203A shows a straight exponential horn, the dotted lines representing equal lengths along the horn, and Fig. 203B shows the same horn coiled up to make it compact. Fig. 203C shows a compact type of "folded" exponential horn designed by engineers of the Bell Telephone Laboratories. The path of the sound waves is shown by the arrows. Notice that the sound path at the unit divides into two identical paths which join at the mouth of the speaker. The superior performance of the "Orthophonic" phonographs is largely due to the use of exponential horns for the sound reproduction. In fact, exponential horns are sometimes called "Orthophonic Horns".

Exponential horns for home use are of the coiled up form and usually use a balanced armature type driving unit. As they are not very pleasing in appearance they are usually enclosed in a console cabinet with the receiver. Fig. 204 shows a 104 inch exponential speaker for home use made by the Racon Electric Company.

The bell is 18 by 24 inches. For large halls or theatres, large exponential horns with powerful moving coil type units are employed. They are also used extensively in connection with talking moving pictures. (See Fig. 291A.)

267. **CONE SPEAKER:** The common type of cone speaker consists of a balanced armature or inductor dynamic type driving unit which is connected by a rod or lever system to the apex of a large conical diaphragm. Fig. 205 shows the lever system used in a popular cone speaker.

The diaphragm or "cone" is usually made of specially prepared paper which resists changes in size and shape due to heat or moisture. In the "fixed" edge cone (Fig. 206) the base of the cone A is fastened to the base of a second cone B (or else to a frame) and the driving rod C extends from the unit D (rigidly fastened to the frame) to the apex of the cone. The diameter of the cone may be anything from about six inches to three feet. For home use, eighteen to twenty-four inches are common sizes. Fig. 207 shows a photograph of the rear of a Western Electric

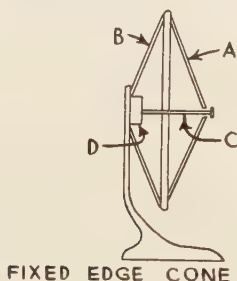


Fig. 206

540 C. W. loud speaker which ranks among the finest of its type. Well-designed and constructed speakers of this type have very good frequency response, some of the 36 inch cones reproducing frequencies below 64 cycles. In most cone speakers an adjustable apex set-screw or chuck arrangement is provided to compensate the small changes in the tension of the paper cone due to atmospheric changes. Cone speakers should always be used with an output filter following the output power tube in the receiver.

The cone type of speaker differs from the horn type in that the vibrated surface communicates directly with the free air. At low frequencies the cone acts as a sort of plunger which pushes the air directly in front and in back of it. At the high frequencies, the inertia of the outside edges keeps them from vibrating while the center or apex region moves, thus tending to make the cone vibrate in sections instead of as a complete unit.

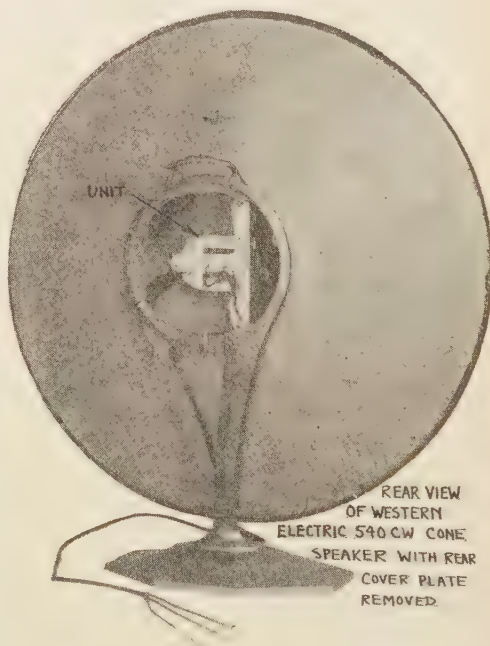


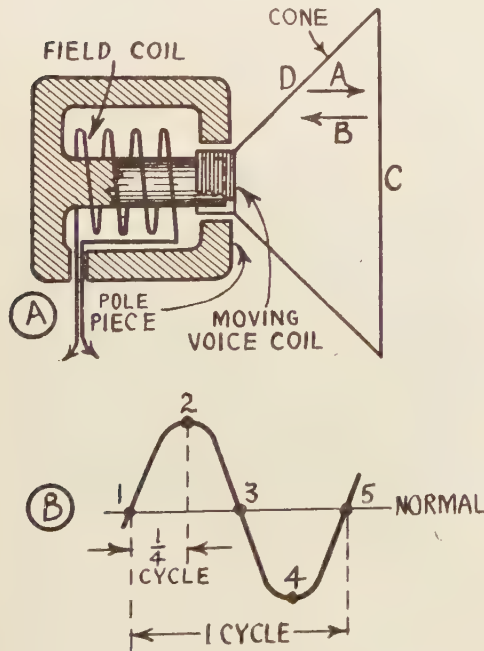
Fig. 207

268. **FREE EDGE CONE:** In a free edge cone (Fig. 208A) the unit "A" drives the paper cone "B" whose base is free to move. The weight of the paper cone is usually supported by mounting it on a rigid ring D by means of a thin flexible leather or chamois ring "L" which allows almost perfect freedom of movement of the cone. This type of speaker being unrestrained in its movement acts more nearly like a plunger or piston, and is capable of excellent reproduction. A commercial speaker of this type, removed from its cabinet, is shown in Fig. 201. The paper of the cone is often moulded in ridges in order to stiffen it and assure true plunger-like movement.

269. **BAFFLES:** Free-edge cone speakers need not have a large cone in order to reproduce the low frequencies, but they should be attached to large baffles. These are necessary because the front and back of a cone speaker sets

up air waves which would alternately reinforce and neutralize each other, and seriously affect the volume of the lower frequency notes if it were not for the baffle.

When the loud speaker is producing sound the cone is in vibration, that is, first it moves forward in the direction shown by arrow A, Fig. 207A, and the next instant it moves in the direction of arrow B. The cone is shown attached to a dynamic speaker driving unit for simplicity. If the audio current flowing through the voice coil has a frequency of say 100 cycles, then the cone moves in the direction A 100 times every second, and in the direction B 100 times every second. Each time it moves in direction A it compresses the air in front of it. At the same time the air in back of it is rarefied or decompressed since the cone on moving forward has left more space behind for the air to fill. These differences in air pressure (more pressure in front and less pressure in the rear), immediately tend to equalize each other and the extra air in front immediately tends to move around to the edge of the cone to the rear where there isn't suffi-



VIBRATIONS OF A FREE EDGE CONE

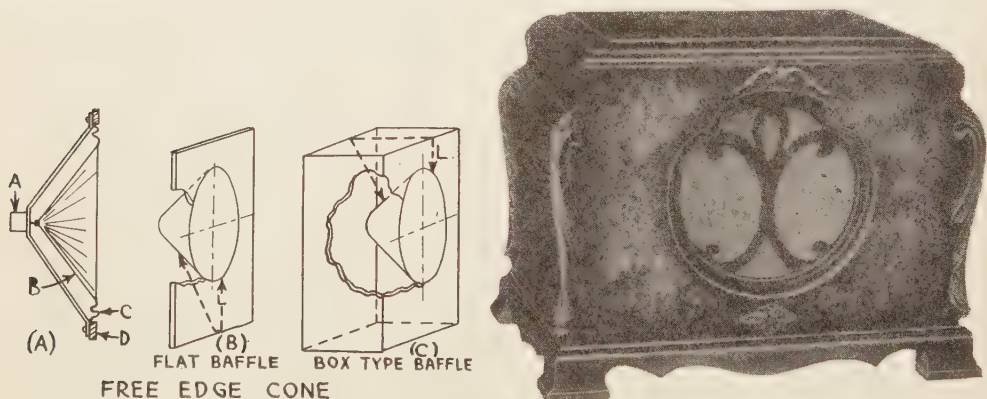
Fig. 207A

cient air. But sounds are caused by movements of air due to tiny air pressures and rarefactions. If these pressures are allowed to neutralize each other, there will be no movement of air out directly from the front or the back of the speaker toward C or D, and hence no sound will be produced. If they partially equalize each other, very little sound will be produced. Consequently something must be

done to prevent the compressed air from getting from the front to the back of the cone *in time to equalize the pressure at the back* (or vice versa).

This is accomplished by placing a baffle around the cone, taking either of the forms shown in Fig. 208. The air must now take the long path L around the baffle in order to get from one side of the cone to the other. By making this path long enough, the air cannot get from the front to the back of the cone (or vice versa) in time to equalize the air pressure, as will now be explained.

It must be remembered that the current flowing through the voice coil is an alternating current (in the case of a speaker coil connected directly in the plate circuit of an output tube without coupling transformer, the current is a pulsating direct current, but the same reasoning also applies to this case). Thus alternating current may be represented by the familiar form shown in part B of Fig. 207A, although the wave form of actual voice currents is much more complicated than this, as shown in Fig. 16D. Since the cone follows the variations in the current, the air pressure variations will follow the same curve. In terms of air pressure in front of the cone, we can decide that from 1 to 2 the pressure is increasing above the normal value. From 2 to 3 it is gradually decreasing to normal. From 3 to 4 it is decreasing below normal. And from 4 to 5 it is gradually



Photo, Utah Radio Products Corp.

Above: Fig. 208 A-B-C; Right: Ornamental Box Type Baffle

increasing to normal. The air pressure in front of the cone, therefore, goes through four distinct changes during one complete cycle (one forward and backward movement of the cone). If the current has a frequency of say 100 cycles there would be four times 100 or 400 changes in pressure per second. Sound waves travel about 1100 feet per second. Therefore, in the case of a 100 cycle note, during any one change in pressure (each of which takes place in one 400th of a second), the sound pressure wave will travel 1100 divided by 400 or 2.75 feet. Keep that in mind for a moment. Now if we allow the pressure wave from the front to go around directly to the back of the cone it will neutralize the rarefaction wave there. But if we make this pressure wave travel around a distance at least equal to 2.75 feet it will take it at least one 400th of a second

to get to the back of the cone. But we calculated that this is the time required for one change in pressure. Therefore, by the time the pressure wave from the front gets to the back, the cone has changed its direction of motion and the back is now producing a pressure wave, so that the two waves do not neutralize each other but actually reinforce each other.

It is evident then that the purpose of the baffle is simply to *delay* the meeting of the front and back sound waves by artificially increasing the distance from the front to the back of the cone. It is evident that to fully reproduce any note the shortest length of the path from the front to the back of the cone (distance L in Fig. 208 B and C) must be made at least equal to the distance the sound travels during the time it takes to complete one quarter of a cycle of that note (see part B of Fig. 207A) or during the time it takes the cone to move from the center position to the extreme position in either direction. The distance the sound travels during one complete cycle is defined as the wavelength of the sound and is equal to the velocity of sound 1084 feet per second) divided by the frequency in cycles per second. Therefore, the length a baffle should be to permit full reproduction of any frequency can be easily calculated by the simple rule, that the baffle length in feet is equal to one-quarter the wavelength of the note to be reproduced. That is,

$$\text{Baffle length} = \frac{1}{4} \text{ W. L.} = \frac{1}{4} \times \frac{1084}{\text{Frequency}} = \frac{271}{\text{Frequency}}$$

A baffle to permit full reproduction of tones as low as 30 cycles must be at least

$$\frac{271}{30} = 9.03 \text{ feet}$$

in effective length (L).

Referring to Fig. 4, the frequency range of the various musical instruments may be seen, and the lowest note which any instrument can produce may be ascertained. To reproduce the lower notes with a free-edge type of cone speaker a baffle must be used. The graph of Fig. 208E shows the minimum size of baffle required for complete reproduction of the various frequencies. These values were calculated by the above formula. The baffle size is given in inches, for convenience. This is obtained by multiplying the values obtained by the above formula by 12. At the top of Fig. 208E the lowest frequencies of the various musical instruments are noted. This chart can be used to determine the size of baffle required for full reproduction of the lowest note of any musical instrument.

A study of Fig. 208E shows that the required length of the baffle air path decreases as the frequency goes up. At 2000 cycles for example the air path need be only 1.63 inches. Since the distance from the front to a point near the center of the back of an ordinary ten inch diameter cone is about five inches, it follows that the cone itself is an effective baffle at the high frequencies. Therefore the baffle is only important at the low frequencies and its size is determined by the *lowest* frequency to be reproduced.

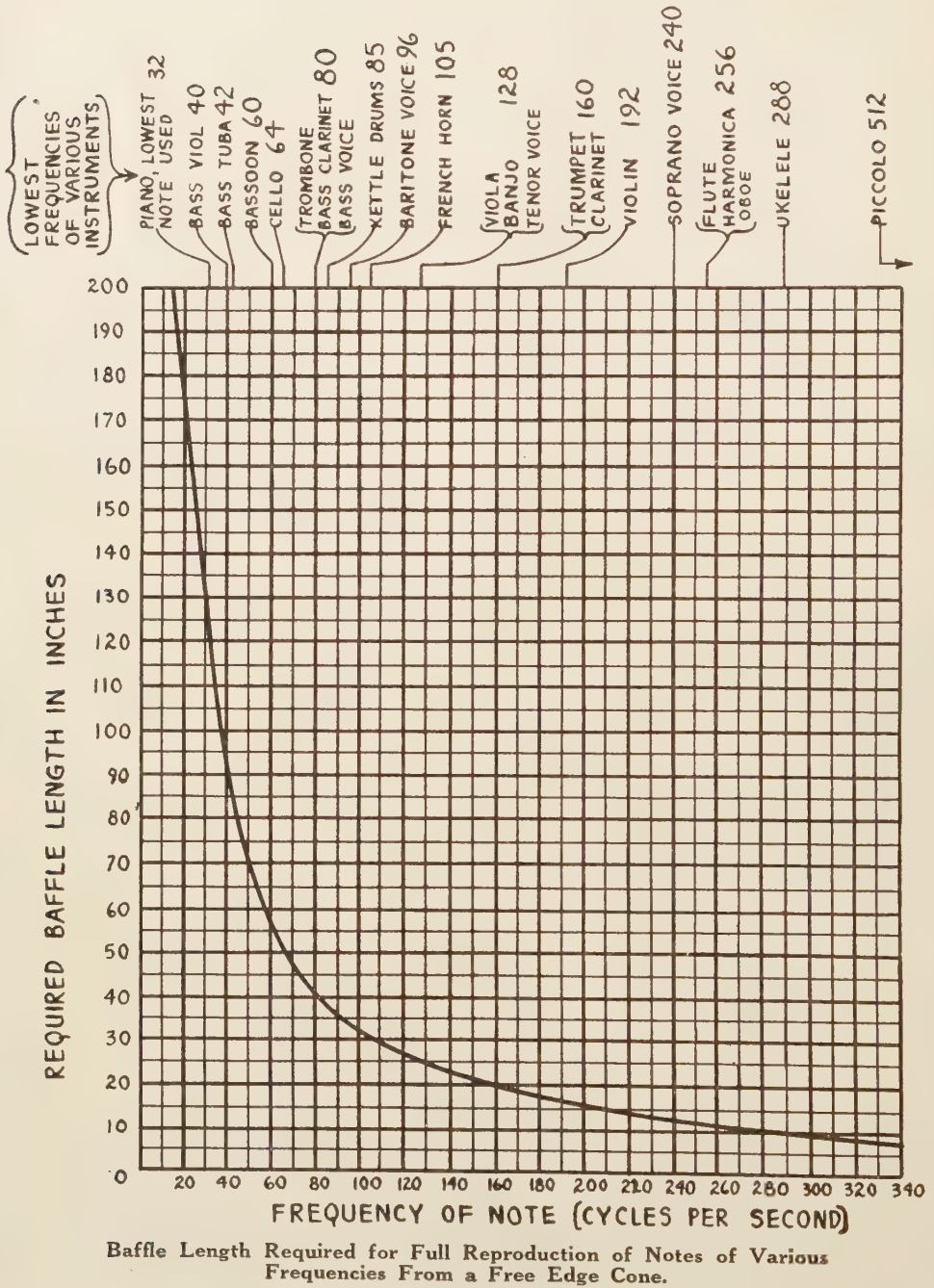


Fig. 208E

It is difficult to define exactly what the baffle length is, since, strictly speaking, all parts of the cone are helping to produce sound. Some authorities define the baffle length as the distance from a point in the center of the front of the cone to a point in the center of the rear. This length would be slightly longer than that taken throughout this discussion. However, as the baffle lengths are usually worked out for low frequencies, and these lengths work out in most cases to 36 inches or more (see Fig. 208E), a difference of an inch or two in considering the baffle length does not make much difference in the result.

As it makes no difference how the length of air path for the baffle is obtained, baffles take many forms in actual practice. Flat baffles are probably the best types as they are not troubled by resonance effects, but their large size and ungainly appearance hardly make them suitable for use in homes. Fig. 208B shows a straight square baffle in position on a cone. In this type the length of each side of the baffle is made equal to the length given in the table of Fig. 208E, since the baffle length is about twice the distance of half a side.

Fig. 208C shows a box shaped baffle which is more compact. This type is used extensively in homes because of its compactness and better appearance. The box type baffle is made up into artistic looking cabinets which blend in with the rest of the furniture in a room. The back of the box or cabinet type baffle should be left open to allow free circulation of the air. If it is closed up or restricted, resonance effects will be set up in the cabinet, resulting in better reproduction of some frequencies than others, and resulting in "barrel tone." Often the response of a cabinet type speaker can be improved by lining it with some non-resonant material such as thick felt, Celotex, etc.

When a dynamic unit is operated in the same cabinet with the radio receiver, the entire system may break into continual oscillation due to the mechanical vibrations being set up in the elements of the detector tube by the sound vibrations.

The remedy for this is to wrap the detector tube in thick felt, or weigh it down with a heavy metal cap to dampen the vibrations.

Fig. 208D shows a horn type of baffle attached to a dynamic speaker. The bell of the horn measures 18 by 30 inches and it is about ten inches deep. It is claimed that a horn baffle is equivalent to a straight baffle of approximately double the size. As a horn it loads the cone with an air column and therefore tends to reduce "blasting" effects. It also tends to make a cone speaker directional.

It must be evident from the foregoing discussion that baffles do not act as "sounding boards" as many people think. They are not supposed to vibrate or

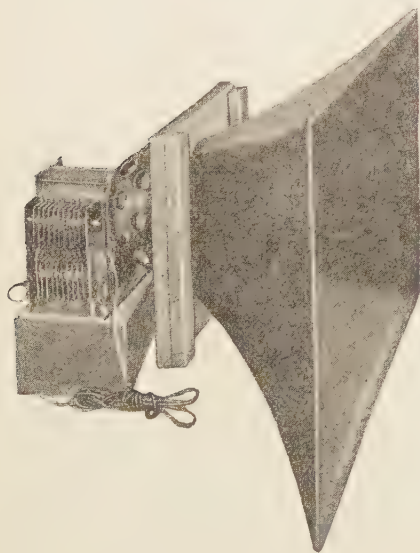


Photo Courtesy Racon Elect. Co.

Fig. 208D—Horn Baffle on Dynamic Speaker

emit sound waves themselves at all, although sometimes baffle resonance effects are designed to accentuate the response of some frequencies which the speaker itself is deficient in. Baffleboards should be made rigid and usually of wood at least three-quarters of an inch thick. Baffleboards made of Celotex, at least one inch thick, are also very good, as this is a non-resonant material. For very low frequency reproduction the wall or ceiling of a room may be used as a baffle by cutting a circular hole in it large enough for the cone to fit through, but usually the volume of sound is reduced by this as the sound waves from the rear of the speaker are not heard at the front.

If a baffle is made smaller than the size required to reproduce that frequency it does not mean that this frequency will be completely suppressed—it simply means that notes of this frequency will be partially suppressed, the extent of this suppression being determined by how much smaller the baffle is than the correct size. If notes below the actual “cut-off” frequency of the baffle are impressed on the loud speaker, the resulting tone is made up mostly of the higher harmonics of these notes. Thus while a baffle may not be large enough to permit of reproduction of a 60 cycle note, it may be large enough to permit of reproduction of the second harmonic frequency of 120 cycles. Thus this note would be partially reproduced, but, of course, not in its true tone. This accounts for the partial low note reproduction effect produced by speakers having small baffles. Of course, it is assumed that the receiving set passes on the low frequency notes to the speaker motor, and that the motor is capable of operating the cone at these frequencies. It would be foolish to design a 55 inch baffle to permit reproduction of 60 cycle notes, for instance, if the set and speaker combination was unable to reproduce any frequencies below 200 cycles. In this case a 16.5 inch baffle would suffice, and the reproduction with it would be just as good on this particular set and speaker as would the 55 inch baffle.

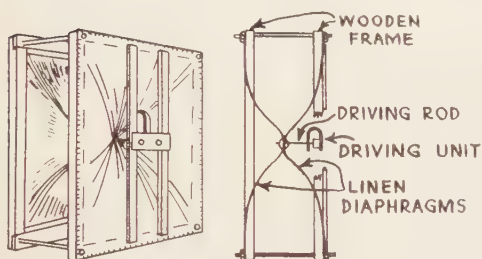
With ordinary receiving equipment it is not necessary to use baffles larger than about 48 inches, since these give a cut-off frequency of about 70 cycles. Very few medium priced commercial receivers really reproduce notes as low as this.

Magnetic speakers of the free-edge cone type are also ideally suited for mounting inside of a radio cabinet and are usually cheaper to construct than the fixed edge type. The construction makes a short driving rod possible and this helps to reduce distortion. They provide practically uniform frequency response over a wide band of frequencies.

270. AEROPLANE CLOTH SPEAKER: The aeroplane cloth or linen diaphragm type of loud speaker has gained wide popularity because of its sensitiveness and the excellent reproduction it is capable of providing. The usual form consists of two square diaphragms of tightly stretched linen (which has been treated with a “dope” to stiffen it) as shown in Fig. 209 on parallel wooden frames with the centers of the diaphragms drawn together and connected to a loud speaker driving unit, of the balanced armature inductor dynamic, or moving coil type, at this point. One diaphragm is usually larger than the other. The large diaphragm reproduces the low and middle frequencies while the small diaphragm reproduces the high frequencies. The large diaphragm may be anywhere from 18 to 48 inches or more square.

This type of speaker possesses several good mechanical features. As the tensions of the two diaphragms perfectly balance each other, the slightest vibration of the speaker unit produces an audible sound. This also improves the reproduction because the load on the speaker driving unit is equal in both directions.

The highly taut diaphragms make it difficult to overload the speaker when it is used with a good driving unit, and this avoids the rattling which is so frequently observed in cone speakers.



AEROPLANE-CLOTH SPEAKER

Fig. 209

271. THE ELECTRO-DYNAMIC CONE SPEAKER:

The electro-dynamic cone speaker has become very popular because of its ability to handle large amounts of power and reproduce the low notes faithfully. It usually consists of a combination of small free-edge cone with a baffle and a moving coil electro-dynamic driving unit of the type

explained in Article 255 (see Fig. 193). The cones used vary from about six inches in diameter for the smaller units to about twelve inches for the large units. The paper cone is attached rigidly at its apex to the moving coil. The outside edge of the cone is fastened loosely by some soft and flexible material, such as thin leather, to an outside rigid supporting ring. Two or three thin flat metal or laminated Bakelite springs keep the moving coil centered in place in the air-gap and sometimes the metal ones also act as conductors of current to the coil. The cone is thus almost "full-floating". The resonant frequency of the cone, coil, and spring combination should be made very low, usually less than 50 cycles per second, so that the speaker acts as practically a non-resonant pure resistance load on the amplifier for most of the working audio frequency range. The photographs of Figs. 194 and 197 show two dynamic speakers designed for home use.

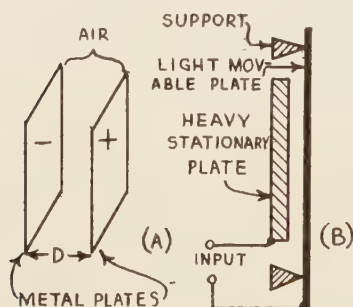
The moving coil construction allows of large vibration movements of the cone, without causing rattle in the driving unit. For the reproduction of very low notes at loud volume, the cone may move as much as one-half inch in this type of speaker. The movement is back and forth like a piston in an engine. Baffle boards of some kind are always necessary if the low notes are to be reproduced. Fig. 208D shows a horn type baffle installed on a dynamic speaker. The frequency response of this type of speaker is exceedingly good. Dynamic cone speakers are built complete for operation on 110 volts A. C. current and contain the coupling transformer and rectifier inside the housing. Other types are built for field excitation from a six volt storage battery and still others are built for operation from the 110 volt D. C. lighting circuit.

272. CONDENSER-TYPE LOUD SPEAKER: A loud speaker known commercially as the "condenser" or "electrostatic" speaker has recently appeared in commercial form. It utilizes the principle of the electrostatic attraction and repulsion of two electrically charged plates in accordance with the well known principle of electrostatics that "like" charges repel and unlike charges attract.

At this writing it is difficult to tell just what practical form the speaker will

take when it is finally perfected. It is safe to say, however, that its operation will be substantially as described for the simple speaker following.

273. **THEORY OF CONDENSER-TYPE SPEAKER:** When two conductors of electricity are separated in space by a non-conductor of electricity, we have what is called an electrical condenser. If these two conductors are charged with electricity of like sign, they tend to repel each other and if they are charged with electricity of unlike sign, they tend to attract each other. Suppose that these two conductors are large, flat, metallic plates of equal area, separated by a thin film of air. (See Fig. 210A.) If a difference of potential or voltage is applied to these plates, a force will be exerted tending to draw these plates together, and the force will be proportional to the area, A , of one side of one plate; it will be proportional to the square of the voltage between the two plates; and it will be inversely proportional to the square of the distance, D , between the two plates.



SIMPLE CONDENSER LOUDSPEAKER

Fig. 210

will tend to move in and out at double the frequency of the applied voltage which, in this case, would amount to 120 times per second. This result would be obtained since the plates tend to pull together both on the positive and on the negative halves of the alternating-voltage cycle. Thus instead of obtaining a 60-cycle tone by virtue of the motion imparted to the surrounding air by the movable plate, we would obtain a 120-cycle tone. This is a perfect instance of complete distortion, since the original tone is absent and is replaced by one of entirely different frequency.

Suppose that this alternating house current be replaced by the voice current from the output of a broadcast receiver. Then the light movable plate, which we shall henceforth call the diaphragm, would produce a hopelessly distorted sound since it would move in accordance with the square of the voice voltage and at double the voice frequencies.

275. **POLARIZING VOLTAGE:** Let us see how these essential difficulties are minimized. Suppose that we place a high direct voltage, for example 500 volts, across the plate of our crude condenser loud speaker. There will be a strong constant attraction between these plates, due to this constant direct voltage. If now we superimpose a much smaller 60-cycle voltage upon these same plates,

From the above it is seen that the greater the voltage the greater the force, the larger the size of the plate the greater the force, and the smaller the distance between the plates the greater the force. If we make one of these plates quite heavy and stationary and the second plate very light and movable (see Fig. 210B) the application of a varying voltage to these plates will tend to draw the light movable plate to the heavy stationary plate with a force which will increase as the square of the voltage. If an alternating voltage (for example the usual 60-cycle 110-volt house current) is applied between the two plates, the movable plate

this alternating voltage will tend to increase and decrease slightly the direct potential which we have already established between the plates. In other words, the force will alternately become a little greater and a little less than the initial force due to the direct voltage.

It can be shown mathematically, that the motion of the diaphragm under these conditions will be approximately in accordance with, and proportional to the alternating voltage applied between the plates. The smaller the ratio of the alternating voltage to the constant applied direct voltage, the more accurately the diaphragm will follow the alternating voltage variations. It is exceedingly important to note that there will always be a component of the motion which is *twice* the frequency of the original voltage and also that the motion will never be *exactly* directly proportional to the applied alternating voltage. In other words, in this type of loud speaker, as well as in the magnetic and electro-dynamic types, there is always some inherent distortion. A mathematical analysis of the condenser loud speaker shows that the greatest response is obtained when the plates are as close as possible together and both the constant direct voltage and the alternating applied voltage are as great as possible.

274. LIMITATIONS OF CONDENSER-TYPE OF SPEAKER: We have just shown that the alternating voltage must be a small fraction of the direct voltage in order to minimize distortion. This, therefore, is the first limitation. Second, the direct voltage, which is usually called the polarizing voltage, must not be increased beyond 500 or 600 volts because of the danger of break-down between the fixed plate and the diaphragm. Further, it is not safe nor practical to generate much higher voltages than 600 for such a purpose. Third, the distances between the plates cannot be made indefinitely small for several reasons: (a) because the polarizing voltage would tend to puncture the insulation between the two plates (in this case, air) if the distance were too small; (b) there must be sufficient distance so that the diaphragm may move back and forth in order to impart a mechanical wave motion to the air in front of it; (c) if this distance were too small, the diaphragm might actually strike the stationary plate causing a short circuit if too great a voice voltage were applied or if resonance obtained either in the electrical circuit or in the mechanical construction of the loud speaker. Hence, it is seen that compromises must be effected throughout the design of this type of loud speaker just as in the case of the magnetic and electro-dynamic loud speakers considered in previous articles.

As a result of these compromises, the sensitivity and efficiency of the condenser loud speaker is, in general, low. Due to the small permissible distance between the diaphragm and the back plate the large amplitudes of motion necessary for the adequate radiation of low tones is difficult to attain in a practical speaker. This makes it difficult to obtain adequate response at the low frequencies.

275. ADVANTAGES OF CONDENSER SPEAKER: One of the main advantages of the condenser-type speaker is its simplicity and its very low cost. It has but one movable part and contains no coils or magnetic field construction. It can be made very compact.

The diaphragm is attracted as a whole over the greater part of its surface, instead of being actuated at a point, as in practically all magnetic and electro-dynamic constructions. This reduces the effects of complicated modes of vibra-

tion of the diaphragm with resultant multiple resonances, and makes possible a smooth frequency-response curve.

Another advantage is the practicability of using exceedingly thin non-magnetic diaphragms of great flexibility and low inertia, thereby making possible the reproduction of the higher audio frequencies. Also a large flat surface is usually better adapted to the radiation of sound than a cone or horn, since directional effects are reduced.

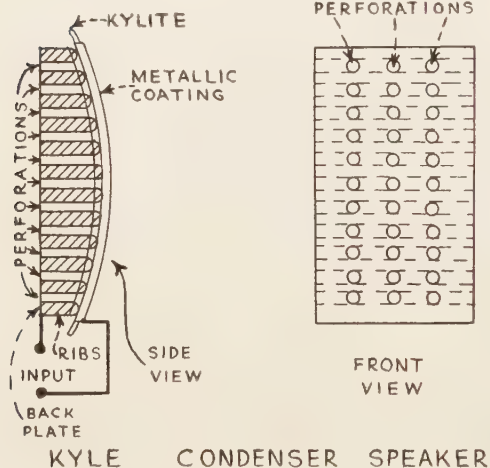


Fig. 211

In the condenser speaker developed by Mr. Colin Kyle, the back plate is covered by a stretched rubber-like material called "Kylite," on the outer side

276. PRACTICAL CONDENSER SPEAKER: The back or stationary plate of the practical condenser speakers are rigidly made of stiff metal, usually either iron or aluminum due to their low cost. The back plate is usually perforated (Fig. 211 and Fig. 211A) to permit free passage of air between it and the diaphragm in order to minimize the loss due to air damping between the plates.

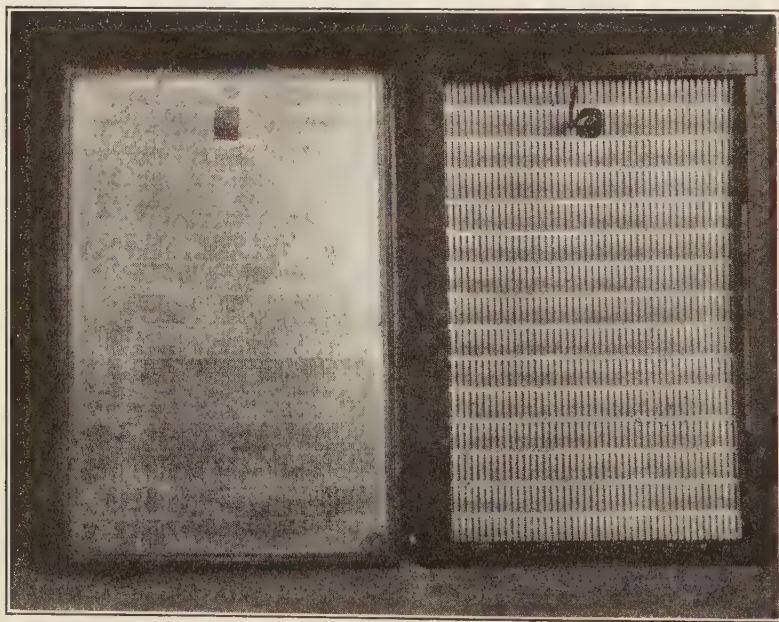


Fig. 211A—Rear and Front Views of Commercial Condenser Speaker

Photo United Reproducers Corp.

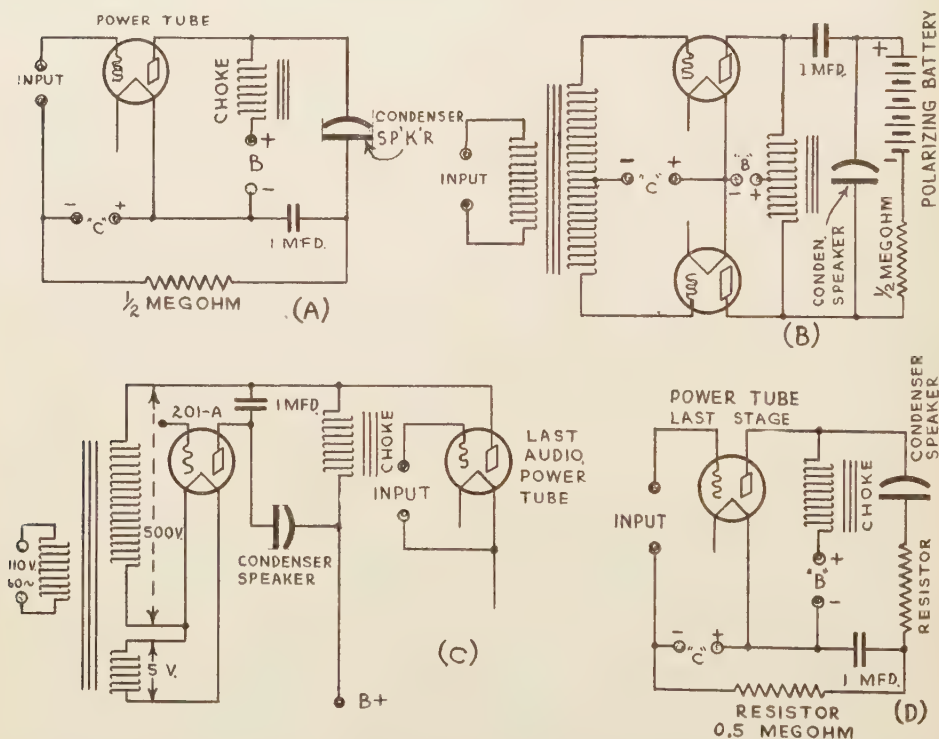
of which is cemented a thin flexible conducting coating which serves as the diaphragm. The thickness of the Kylite dielectric is about 0.005 inches and it has a dielectric constant of about 3. This loud speaker is constructed in units 8 inches by 12 inches. Any number of these may be connected in parallel in order to give a large surface from which to radiate the sound. The capacity of each section of the Kyle speaker is about 0.004 microfarads.

Just as with loud speakers of the free-edge cone type, it is necessary to use a baffle board or baffle cabinet in order to radiate the lower audio-frequency tones. The same rules apply to the calculation of baffles for this purpose as in the case of electro-dynamic loud speakers.

277. CONNECTIONS OF CONDENSER SPEAKER: The radio set and associated audio-frequency amplifier must have the same properties as those required for good reproduction with magnetic and electro-dynamic loud speakers with the exception of the arrangement of the circuit for the output of the last audio-frequency stage, and the provision of a suitable polarizing voltage. Whereas the impedance of the electro-dynamic type loud speaker is usually very low, averaging approximately 25 ohms at 1000 cycles, and the impedance of the average magnetic-type loud speaker is about 5,000 ohms at 1000 cycles, the impedance of the condenser-type loud speaker is very high; that is, of the order of magnitude of 50,000 ohms at 1000 cycles. It is, therefore, evident that circuit arrangements must be somewhat different in the case of the condenser loud speaker in order to obtain the proper impedance relationship. If a transformer is used to couple the loud speaker with the output tube of the audio frequency amplifier, it must have a step-up ratio instead of a step-down ratio such as is usually employed for other types of loud speakers. The last tube may be impedance coupled as shown in Fig. 212 A. However, if a low plate impedance power tube is used in the last stage, this is a very inefficient method of connection. A method for connecting this loud speaker with the push-pull amplifier is shown in Fig. 212 B. Where the last tube in the set is a power tube, such as the 210 or 250, the "B" voltage may also be used as the polarizing potential for the condenser loud speaker, as shown in Fig. 212 A. Sometimes it is desired to use a separate source of polarizing voltage in which case a step-up transformer, a 201-A type tube, and a 1 mfd. filter condenser are connected as shown in Fig. 212 C, to provide the polarizing voltage. As the polarizing voltage is operative only when connected so as to give a close D.C. path for the biasing charge, a $\frac{1}{2}$ megohm grid leak resistor has been shown in these diagrams where the output circuit contains a condenser. This completes the D.C. path, and the 1 mfd. condenser allows the completion of the A.C. path through the speaker.

Since the impedance of the condenser-type loud speaker is inversely proportional to the frequency, the division of voltage between the resistance of the last stage tube and the condenser-type loud speaker will change with the frequency; the voltage across the loud speaker being greatest at low frequencies and smallest at high frequencies. This quality can be compensated by proper design of the coupling transformer or by the introduction of resistance in series with the condenser-type loud speaker as shown in Fig. 212 D. The resistor used must be of the best quality in order that no extraneous noise shall be introduced into the loud speaker circuit. The latter method improves the fre-

quency-response characteristic at the expense of the sensitivity of the loud speaker, hence a compromise must be effected between the two. A value of about 15,000 ohms is recommended for a single section Kyle speaker, about 25,000 ohms for four sections, etc. It is, of course, possible to design the audio-frequency amplifier of the receiving set in such a manner as to have a rising frequency-response characteristic which will compensate the falling frequency-response char-



POSSIBLE CIRCUIT ARRANGEMENTS FOR CONNECTING CONDENSER LOUDSPEAKER TO OUTPUT POWER TUBE OF RECEIVER

Fig. 212

acteristic of the condenser-type loud speaker. In this way, a maximum response may be obtained with a very flat frequency-response characteristic.

278. FUTURE OF CONDENSER SPEAKERS: The design of condenser-type speakers for home use may take the form of a tilt top table, a tapestry hanging on a wall, etc. It is only about one-eighth of an inch thick. It is difficult at this time to predict the future of this type of speaker. It has advantages and disadvantages just as all other types of loud speakers do. With present day high power amplifiers the question of good frequency response in loud speakers is becoming more important than that of sensitivity, and if it can

be shown that practical condenser-type loudspeakers are capable of better frequency-response characteristics than magnetic or electro-dynamic types, this type of speaker should become popular on account of its extreme simplicity and low cost.

279. LOUD SPEAKER RESULTS: While some loud speakers are theoretically inherently better than others, they may not be so in practice due to incorrect design. A dynamic speaker due to poor design, may be much inferior to an average cone or horn speaker, or vice versa. It is safe to say that either the exponential horn, the fixed or free-edge cones or the dynamic cone speakers will give excellent results if designed and constructed right and used intelligently with a consideration of the characteristics of the audio amplifier employed, and the results desired.

280. DESIRABLE CHARACTERISTICS: The desirable characteristics of the loud speaker depends on the audio amplifier with which it is used (assuming no sidebands are cut in the R.F. amplifier). If the A.F. amplifier approaches the ideal type, i.e., amplifies all frequencies from about 32 to 8000 cycles equally, then the ideal speaker for use with this amplifier should reproduce all frequencies from 32 to 8000 cycles equally well, in order to preserve perfect quality. The problem in A.F. amplification and sound reproduction is the equal reproduction of all frequencies for a definite voltage input, in other words, uniform sound output from the loud speaker. While it is possible to construct an A.F. amplifier which has practically a flat characteristic curve from 32 to 8000 cycles per second, the loud speakers available at the present time have definite frequency limitations. There is no commercial speaker made which to the writer's knowledge has a flat frequency characteristic over this range. Most speakers fall off in response at the very low and at the very high frequencies, but this can be partly compensated for by proper design of the audio amplifier.

281. COMBINING CHARACTERISTICS: If definite knowledge regarding the frequency-response of a certain loud speaker is at hand, the audio-frequency amplifier for use with it can be designed to supplement the loud speaker at its weak points, that is, on certain frequencies where the loud speaker is deficient, the amplifier can be designed to increase the response and conversely where the loud speaker response is more than normal, the amplifier should be arranged to reduce the response. As an example of this, Fig. 213A shows the response curve of a long horn speaker. The extremely low notes are weak, the middle frequencies normal and the high frequencies weak. Obviously the amplifier should be designed to have the response shown in Fig. 213B, with low and high frequency-response exaggerated and relatively lower output in the middle register. The approximate resultant response curve of the speaker and horn combined is shown in Fig. 213C. Notice that the deficiencies of the speaker have been nearly corrected by proper design of the A. F. Amplifier. Obviously this amplifier would only give these good results when used with this particular type speaker, if another speaker were used the resulting response would be totally different.

Transformer coupled or shunt feed coupling by the Clough system lends itself nicely to this sort of work, since the amplification characteristic of the transformer can be modified easily. Also certain frequencies can be suppressed by band filters, or strengthened by resonant circuits. This practice of making up

for the deficiencies of one electrical circuit by over-exaggerating the corresponding characteristics in another circuit in a system, is used extensively in telephone work.

It is evident from a study of the curves of Fig. 213 that any type of loud speaker will not operate equally well with any audio amplifier. This is the reason why a certain loud speaker will appear to work very well with a certain set and will give only average results when connected to a different receiver. As a matter of fact an audio amplifier having ideal straight line frequency response intensifies the poor frequency response of a loud speaker of average worth as shown in Fig.

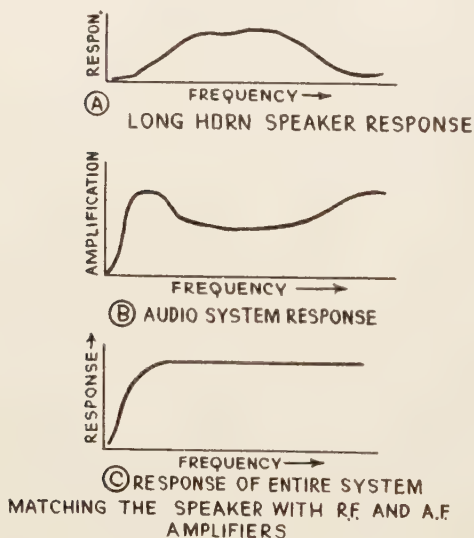


Fig. 213

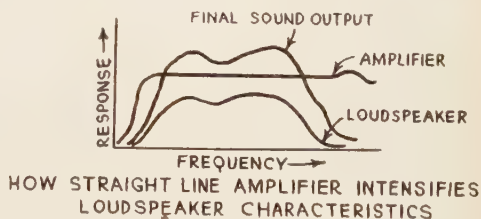


Fig. 214

214 and really makes it sound worse than it might when used with a less perfect amplifier whose frequency characteristics just happen to fit in with it.

It must be kept in mind, however, that the difference in hearing facilities of different persons makes it impossible to produce one sound-reproducing system which is absolutely satisfactory to every person. Compromises must be effected. Some persons are pleased with repro-

duction where all of the low notes are reproduced. Others are pleased with reproduction which includes only part of the low note range, etc.

REVIEW QUESTIONS

1. What is the function of the loud speaker in the radio receiving system?
2. What is a loud speaker "unit" or driving motor? Name three types of driving motors.
3. Explain the operation of the iron diaphragm type of unit. What are its disadvantages?
4. Explain the operation of the balanced armature type of unit. What are its advantages and disadvantages?
5. Explain the operation of the moving coil type of unit. What are its advantages?
6. Describe the construction and operation of an electro-dynamic speaker designed to have its field operated from 110 volts A. C. Why is the rectifier used?

7. What is the function of the coupling transformer between the plate circuit of the power tube and the loud speaker coil?
8. Explain the operation of the inductor dynamic speaker unit. What are its advantages?
9. What is the function of the horn on a loud speaker. What characteristics should the horn material possess?
10. What is an exponential horn? What determines the cut-off frequency of an exponential horn?
11. What is a cone speaker? Define free-edge cone, fixed-edge cone.
12. What is the function of the baffleboard used with a cone speaker? What baffle length is required for full reproduction of the 40 cycle note of a bass viol by a free-edge cone?
13. What is the principle of operation of the condenser type loud speaker? Why is a polarizing voltage used?
14. What are the limitations of the condenser speaker? What are its advantages?
15. Draw a diagram of a condenser type speaker connected to a power output tube of a receiver, showing the necessary polarizing voltage tube.
16. What characteristics are desirable in a practical speaker used with the ordinary receiver?

CHAPTER 17

FOUR-ELECTRODE (SCREEN-GRID) TUBE

FOUR-ELECTRODE TUBE—REVIEW OF TUBE ACTION—FOURTH ELECTRODE—SPACE CHARGE TUBE—SCREEN-GRID TUBE—UX-222 TUBE—USE AS R. F. AMPLIFIER—COUPLING METHODS—TRANSFORMER COUPLING—TUNED PLATE COUPLING—AUTOTRANSFORMER COUPLING—CHRONOPHASE SYSTEM—GRID BIAS—STABILITY AND SHIELDING—SELECTIVITY—DETECTION—AUDIO AMPLIFIERS—AUDIO SYSTEMS GENERAL—A. C. FOUR-ELECTRODE TUBE.

282. **FOUR-ELECTRODE TUBE:** Probably no radio development during the past few years has created such widespread interest as the screen-grid four-electrode tube.

The four-electrode tube provides two very desirable characteristics when used as an amplifier tube, namely, a theoretical amplification factor of about 300 and eliminator of internal capacity feed back effects between grid and plate. The desirability and actual attainment of these will be discussed in the above order for convenience.

283. **REVIEW OF TUBE ACTION:** Before proceeding with a discussion of the four-electrode vacuum tube, a short review of the operation of the three-electrode tube will no doubt prove helpful.

The incandescent filament gives off negatively charged electrons. The positively charged plate attracts these, producing a plate current. In the path of these moving negative electrons is placed a grid which can be made to control the electron flow and plate current, by varying its potential. A negative grid repels the electrons and overcomes a portion of the plate's attraction for them, thus decreasing the plate current (Fig. 43C). A positive potential assists the action of the positive plate, and increases the plate current (Fig. 43B).

The amplifying effect of the tube is due to the fact that since the grid is closer to the filament than the plate, a slight grid potential change, causes a greater plate current change than an equal plate potential change would. The amplification factor of an ordinary 201-A type tube is about eight.

The space around the filament is filled with a cloud of negative electrons, which constitute a space charge. This negative cloud repels the negative electrons attempting to shoot out from the filament, and being closer to the filament than is the grid, it has a greater effect than the grid. The space charge produces two effects on the operation of the tube:

The space charge constitutes a constant opposition to the attraction of the positive charge of the plate for the negative electrons from the filament. To overcome this constant repulsion, nearly 85 per cent of the plate potential applied

to the tube is used up (this part of the plate potential being practically useless as far as amplification goes), leaving about 15 per cent for direct action on the filament to establish the plate current and produce amplification. It is evident then that if the space charge could be entirely eliminated for equal results, the plate voltages necessary for tube operation would be only about 15 per cent of what they are with 3 electrode tubes, and the plate supply problem would be very much simplified and cheapened.

The second effect of the space charge is to lower the amplification constant of the tube, since the grid does not have perfect freedom in controlling the plate current flow. In practice the tube is always operated with the grid negative. As the repelling effect of a negative grid is added to the existing repelling effect of the space charge, any small change in grid potential is only a small percentage of the total repelling potential. That is, if the space charge were eliminated, the grid effect would be many times what it is with the space charge present, and (with nothing else happening) the amplification factor of the tube would be raised from eight up to 30 or 40, without any change in plate impedance.

Of course, the amplification factor can be increased as is done in ordinary high mu tubes (Chapter 7) by increasing the fineness of the grid mesh and placing the plate *relatively* further from the filament than the grid. But this increases the plate to grid capacity enormously and increases the plate impedance, thus making these tubes usable only in A. F. circuits, due to the difficulties brought about by excessive feedback when used at the high frequencies existing in radio frequency circuits, and the difficulty in securing the proper high impedance load necessary in the plate circuit of the interstage coupling device to obtain any appreciable gain. If an ordinary 3-electrode high mu tube such as the type 240 were to be constructed to have a mu of 200, the plate impedance would be about "*six million*" ohms! The effect of the space charge in ordinary three element tubes is far greater than the effect of the grid, and is a constant factor unaffected by the incoming signal, and tending always to reduce the amplification of the tube.

284. **FOURTH ELECTRODE:** The space charge effect can be overcome or at least reduced practically by putting a *positive charge at or near the region where the negative space charge accumulates*. This is done by introducing a positively charged fourth electrode into the tube, whose purpose it is to assist the work of the plate and do this efficiently because of its being nearer the troublesome cause.

285. **SPACE CHARGE TUBE:** It is evident that this fourth electrode must surround the filament, can be placed either between grid and filament or between grid and plate, and must be of open construction to permit the electrons to fly through it. It can be in the form of another grid, an open winding or a network. If this electrode is placed around the filament between the ordinary control grid and the filament (Fig. 215) the tube is known as a "Space-Charge" grid tube. Circuits and characteristics of the tube connected in this way will be discussed later. The main advantage of this fourth element, if it was built into an ordinary tube and connected in this way, would be a large increase in amplification without appreciable increase either in plate impedance or grid to plate capacity. The connection of the tube in a practical radio frequency amplifying circuit would present no special novelties other than the connection of the

fourth electrode directly to a tap on the "B" battery or "B" supply device, as shown in Fig. 216, for obtaining the proper positive potential.

286. **SCREEN-GRID TUBE:** If the fourth electrode is placed between the grid and plate (Fig. 217) the tube is known as a "screen-grid" tube since the grid is "screened" or shielded against the "plate effect". Here again, since it is kept at a positive potential with respect to the filament, it nullifies the space charge effect, and the grid is made more fully effective in controlling the plate current, resulting in a high μ . But simultaneously, by this position, the capacity *effect* between the plate and grid is reduced to a very low value, thus making the tube very valuable for use as an R. F. amplifier.

The positive grid is maintained at a constant positive potential by connecting it to a tap on the "B" battery. The fact that it is in effect a metallic screen between the grid and plate makes it act as a grounded shield, since there is a complete circuit back through the "B" battery to the negative end of the filament. The resulting effect is that of splitting the capacity between the grid and plate into two capacities, C_1 and C_2 , in series as can be seen in Fig. 218. This is the same result as that produced by introducing a grounded plate between two condenser plates. The screen-grid completely surrounds the plate and the lines of electric force which in the three-electrode tube run from plate to grid are now intercepted by the screen. Hence as the screen is grounded to the filament line through the circuit, only a few of the lines of electric force pass through the screen to the control grid with the result that the capacity is very small.

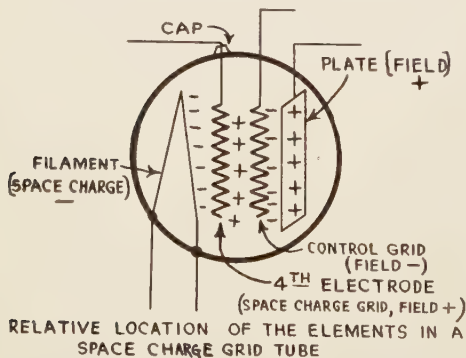


Fig. 215

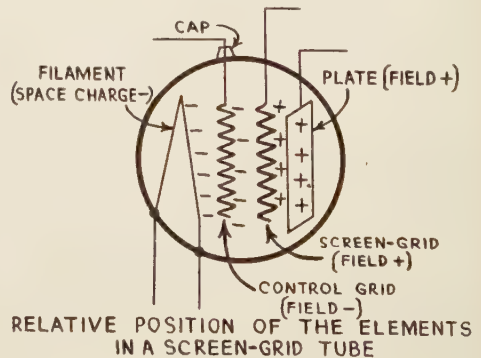
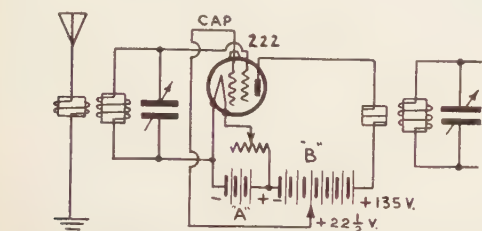


Fig. 217

As the two capacities are in series, the resultant *effective* capacity between plate and grid is smaller than either one of the two, and hence it is reduced to a very small value. The grid-plate capacity of a UX-201A tube is about 10 micro-microfarads while that of a UX-222 (battery type) screen grid tube is about 0.025 micro-microfarads. It is evident then, that the screen-grid tube is very desirable as a radio frequency amplifier from the standpoint of high amplification factor and low grid-plate capacity with resulting self stabilization and elimination of neutralization and oscillation control devices (provided all other sources of feed-

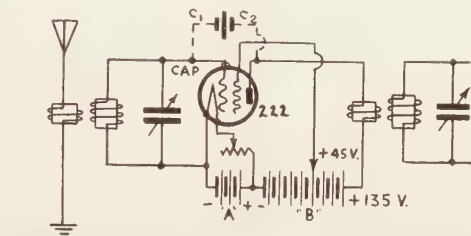
back are eliminated). Greater advantages are secured for practical purposes than when the positive grid is placed between filament and grid.

287. **UX-222 TUBE:** Fig. 219 shows a cut-away view of a commercial form of battery type 4-electrode tube. Externally it resembles one of the ordi-



CONNECTIONS OF A SINGLE STAGE T.R.F. AMPLIFIER USING 4-ELECTRODE TUBE AS A SPACE CHARGE GRID TUBE

Fig. 216



SINGLE STAGE T.R.F. WITH 4-ELECTRODE TUBE AS A SCREEN-GRID TUBE, REDUCTION OF GRID TO FILAMENT CAPACITY RESULTS.

Fig. 218

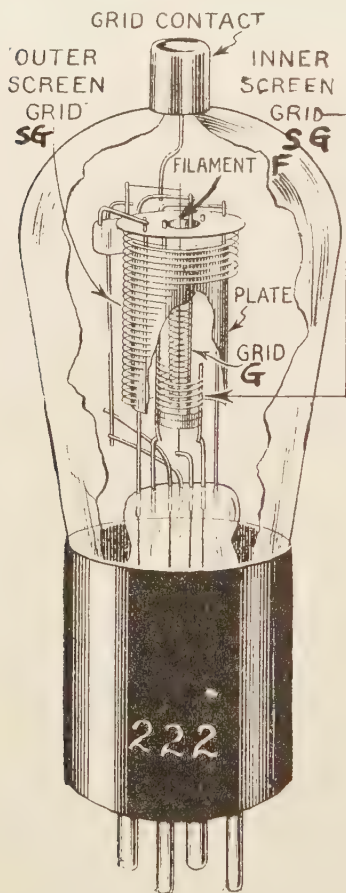
nary 201-A type tubes. It is equipped with a standard four prong base and a fifth connection to a metal cap on top of the glass bulb. This cap is the control grid connection, corresponding to the usual tube grid. The four prongs are divided into two large prongs as usual for the filament. The other two are for the usual plate and the screen-grid. The screen-grid is connected to the prong which corresponds to the grid prong in the UX-201A type tube. The screen-grid connection goes to the proper tap on the "B" battery (either $22\frac{1}{2}$ or 45 volts, depending on the purpose) to give the positive screen bias. The characteristics are listed in the Tube Chart of Fig. 54.

Referring to Fig. 219 and starting at the inside, we see a vertical filament wire (F), stretched taut by two supporting bracing wires. Surrounding this is the spiral wire control or inner grid G, about one-eighth inch in diameter. This is connected to the upper metal cap on the glass tube, to prevent the capacity which would exist between lead-in wires if it was brought out to a prong on the base of the tube. The screen-grid is structurally double, consisting of two fine spirals of fine wire or a perforated screen SG, connected together inside the tube to act as a single element. One of these is located between the inner grid and the inner surface of the cylindrical plate, while the other surrounds the outer surface of the plate. The outer portion shields the plate against the capacity effect of its surface in relation to the connecting wires around it. The arrangement of the elements as they appear when looking down on top of the tube is shown in Fig. 220. The 222 type tube can be used either as a screen-grid tube (Figs. 217 and 218) or as a space-charge grid tube as in Figs. 215 and 216. The characteristics are given in Fig. 54.

In future references the grid SG which encloses the plate will be called the outer grid, to distinguish it from the inner grid G. This is necessary to distinguish them when speaking of the tube as a shielded grid or space-charge grid amplifier since in the former case the inner grid is the control grid and in the latter the outer grid is the control grid. The "control" grid is really the name which has been adopted in place of the "grid" of the 3-electrode tube,

A study of the diagrams will reveal that the tubes are connected up almost in the same way as ordinary tubes with the exception of the positive grid connection. It should be remembered that all tubes having two grids are not necessarily screen-grid tubes. For many years there have been vacuum tubes having two grids, but both grids were used as control grids.

288. **CHARACTERISTICS OF UX-222:** Some idea of the normal characteristics of the 222 type tube can be obtained by means of the circuit shown in

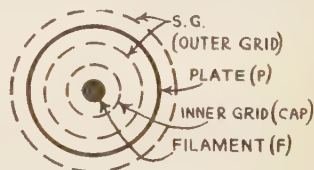


Battery Type 222 Screen-Grid Tube

Fig. 219

with those of an ordinary 201-A type Chapter 5.

As the shielding grid has a potential of $+45$ volts applied to it, it acts somewhat as a plate and a current flows in its circuit. Since the potential is low and the shielding grid has a smaller area due to its open construction than the



ARRANGEMENT OF ELECTRODES IN A UX 222 SCREEN-GRID TUBE

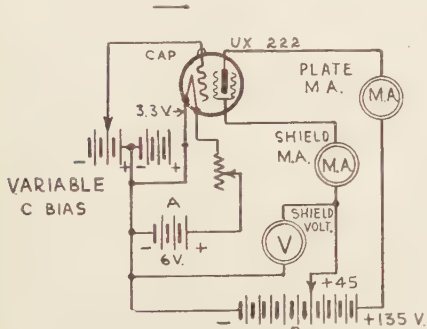
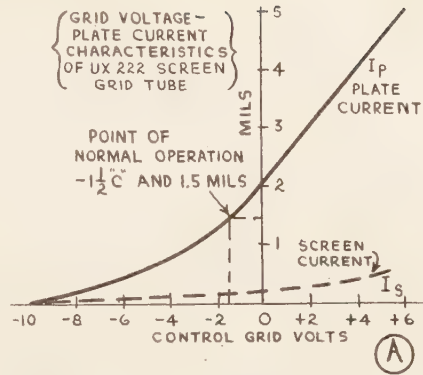
Fig. 220

Fig. 221. Fig. 222A shows the grid-plate characteristic curve for a UX-222 tube with plate voltage of 135 volts, filament voltage of 3.3 V., shielding grid potential $+45$ volts, and control grid voltage varied from -10 V. to $+6$ V. Fig. 222B shows the relation between control grid voltage and plate resistance, amplification factor, and mutual conductance for two values of plate voltage. Fig. 222C shows the relation between plate voltage and plate resistance, mutual conductance, and amplification factor. Notice that the amplification factor and plate impedance vary greatly with change in plate voltage.

In practically all circuits in which the UX-222 tube is used, the control grid is kept at a negative potential with respect to the filament, whether it is used on a screen-grid or a space-charge grid tube. All batteries are returned to the minus filament connection and all voltages have this point as a reference. Compare these curves tube shown in Figs. 45 and 56 of

regular plate, this current in the shielding circuit is very small. Another reason for the small value of this current is the fact that the electrons which are pulled to the screen-grid circuit by the 45 volts are at this point snatched through the screen openings by the much higher plate voltage on the plate beyond. However, the potential on the control grid affects its magnitude. This can be seen from the dotted line of Fig. 222A which represents this screen current.

The filament voltage on the filament of the UX-222 tube is not critical. From about 2.8 volts up to 3.3 volts



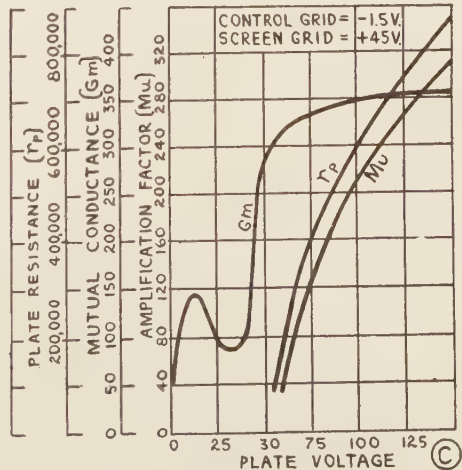
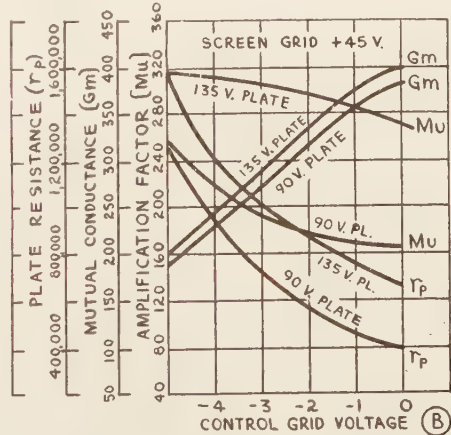
CIRCUIT FOR OBTAINING CHARACTERISTICS OF SCREEN-GRID TUBES

Fig. 221

the plate current increases only slightly.

289. USE AS R. F. AMPLIFIER: The screen-grid tube with its high amplification factor and negligible grid-plate capacity effect is admirably suited for use as an R. F. amplifier. However, any real improvement in performance can come only as a result of careful design and strict attention to the characteristics of the tube.

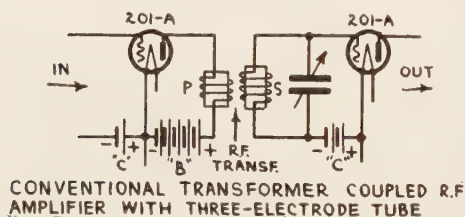
When a 20-A type tube is used in a radio frequency amplifier circuit (Fig.



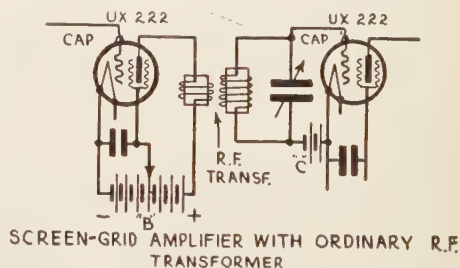
CHARACTERISTIC CURVES OF THE UX 222 SCREEN-GRID TUBE

Fig. 222

223) in connection with an ordinary R. F. transformer, the amplification obtained is a function of the number of turns in the primary coil P and its coupling to the secondary coil S, as explained in Chapter 12. With either a very few or a great many primary turns the amplification is low, but with some definite intermediate number of turns the amplification is a maximum. With a carefully designed circuit and some form of neutralization to overcome plate-grid feedback (which would cause the circuit to break into self-oscillation) it is possible to secure an amplification of about 10 to 15 at 600 meters with this circuit. A higher amplification can be secured either by the use of an ordinary high mu tube such as the 240 type (with its attendant high grid-plate capacity and high plate impedance) or by the use of the screen-grid tube as in Fig. 218.



Left: Fig. 223



Right: Fig. 224

290. **COUPLING METHODS:** High voltage amplification is obtained from a tube used as a voltage multiplier when the impedance of the load in the plate circuit of the tube is equal to the internal plate impedance of the tube. Under these conditions, approximately one-half of the mu of the tube can be realized.

The plate impedance of a UX-201A type tube with 90 volts applied to the plate is only 12,000 ohms. Radio frequency coupling transformers having primaries of 5 to 15 turns and a larger number of secondary turns are quite satisfactory for coupling these tubes. The plate impedance of the tube is fairly well matched by that of the transformer primary at radio frequencies.

The plate impedance of the 222 type tube used as a screen-grid amplifier with a plate voltage of 135 volts and negative bias of 1.5 volts is very high, about 850,000 ohms. Thus, in order to secure high amplification, the impedance of the part of the coupling unit connected in the plate circuit of this tube must be very high, if high amplification is to be secured. The ordinary R. F. transformer with a few primary turns is not suitable, as its primary impedance is too low to work out of the high plate impedance of the shielded grid tube.

Many methods have been devised for coupling the tubes in screen-grid R. F. amplifiers together. In all of them an attempt is made to make the plate load of the tubes of very high impedance. A study of these circuits will now be made. Many of them have already been studied in detail in connection with the chapter on R. F. amplification.

291. **TRANSFORMER COUPLING:** If the screen-grid tubes of an R. F. amplifier are coupled by an R. F. transformer of the conventional type, Fig. 224,

the results obtained depends on the number of turns on the primary coil, the width of the primary winding, and its location with reference to the secondary coil. Good amplification is secured by a transformer having a conventional secondary coil tuned by a .00035 mfd. variable condenser and primary coil having about 35 turns of wire wound to take up a space of one half inch and placed inside and opposite the low potential or grid return end of the secondary. Good results have also been secured with a primary coil of about 35 turns wound to take up a space of 1.5 inches and placed inside of the secondary. While the amplification secured with these two types of coils is nearly the same, the selectivity with the former is slightly greater.

It must be remembered that as there is some capacity and hence capacity coupling existing between the primary and secondary windings, the voltage in the secondary due to this coupling is 180 degrees out of phase with that generated by the inductive coupling, when the winding is continuous in direction from plate to grid. Hence, the amplification is reduced, although the amplification over the entire wavelength band is made more uniform on account of the change in relative energy transfer by capacity and inductance at the various frequencies. This effect can be reduced by winding the primary and secondary coils in opposite directions.

291. TUNED PLATE COUPLING: Fig. 225 shows the tuned plate method of coupling applied to screen-grid tubes. It will be remembered that the objection to this method of coupling with three electrode tubes was that feedback through the plate to grid capacity of the vacuum tube occurred when the plate circuit was tuned to the same frequency as the grid circuit. As the plate to control grid capacity of the shielded grid circuit is very small this action does not take place with the shielded grid tubes.

At resonance the effective impedance between the two ends of the tuned circuit is very high, and so the tuned plate type of amplifier is capable of producing an effective high impedance in the plate circuit.

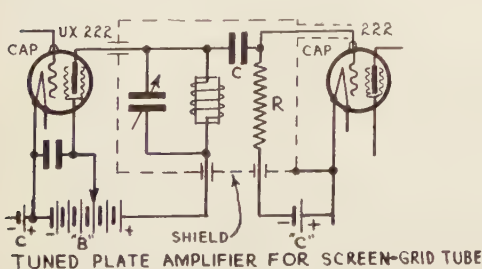


Fig. 225

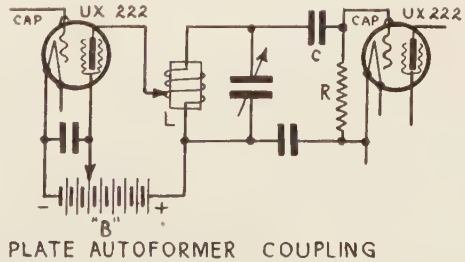


Fig. 226

This circuit has several disadvantages though. The selectivity is rather poor. Also, as the variable tuning condenser elements are at + B potential, the rotor circuit must be insulated carefully from the grounded shielding usually employed in this type of amplifier. Despite this it has been used in modern screen grid receivers.

292. AUTOFORMER COUPLING: Fig. 226 shows a form of coupling in which the screen-grid tubes are coupled by means of an auto-transformer L connected in the plate circuit. The high direct plate voltage is prevented from reaching the control grid of the following tube by the blocking condenser C of about 0.001 mfd. capacity. In this type of coil a portion of the secondary coil acts as the primary, with the primary and secondary currents in this portion of the coil 180 degrees out of phase. The inductive coupling for the same number of primary turns is greater in this type of coil than in one having a separate primary and secondary, hence a greater plate circuit impedance is built up with a relatively small number of turns, resulting in greater overall amplification. The selectivity of this arrangement is good, but the fact that the tuning condenser plates are at the high $B+$ potential is a disadvantage.

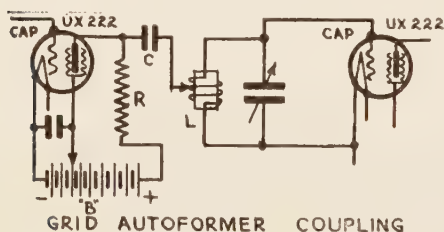


Fig. 227

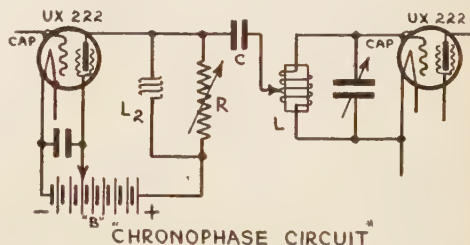


Fig. 228

Fig. 227 shows a circuit in which this disadvantage is removed by connecting the auto-transformer L in the grid circuit and coupling the plate by a high resistance R and condenser C of about 0.001 mfd. The amplification and selectivity obtained with this system is very good.

293. CHRONOPHASE SYSTEM: In the Chronophase System Fig. 228, a radio frequency choke coil L_2 is added to the circuit of Fig. 227 and the resistor R is made variable. This circuit permits of control of oscillation which is sometimes present, due to coupling between grid and plate leads, etc. The plate circuit contains one branch consisting of a resistance R only and another consisting of capacity C and inductance in series, the latter value depending on where the tap is placed on the tuning coil. By varying the resistance, the angle by which the current leads the voltage can be changed, and the tendency toward oscillation controlled (see methods of oscillation control, Chapter 11). The R. F. choke L_2 having a high impedance to radio frequency currents and comparatively low direct current resistance and being shunted around R , maintains the maximum value of $B+$ voltage on the plate of the tube regardless of the value of resistance R . Resistance R is then used as an oscillation control, and if it can be reduced to a low value so as to effectively short circuit C it can also be employed as a volume control for the receiver.

If two stages of R. F. amplification are used, it is only necessary to employ one such resistance in the plate circuit of the first R. F. tube. Maximum results can be obtained by varying the proportion of L which is used in the primary, the amplification (especially on the low wavelengths) is reduced, because the portion

of the coil in which the currents are 180 degrees out of phase is appreciable and hence the voltage at the grid of the following tube is lowered.

294. **GRID BIAS:** When using the UX-222 tube on a 6 volt filament battery, a 10 ohm tap on the 15 ohm fixed resistor placed in the negative lead can be used for securing the 1.5 volt bias for the control grid as shown in Fig. 229. Otherwise this bias can be obtained from a separate 1.5 volt dry cell.

295. **STABILITY AND SHIELDING:** The internal shielding of the electrodes by the screen-grid makes the neutralization of the plate to grid capacity unnecessary. However, screen-grid tube circuits have a very strong tendency to oscillate in spite of the shielding, unless every possible precaution is exercised in reducing to an absolute minimum all sources of feedback external to the tube since the shielding construction only reduces feedback effect within the tube itself. If a tuned plate circuit is used in the R. F. amplifier, the whole connecting circuit between the plate of one tube and the grid of the following tube is at the maximum high radio frequency potential, encountered in the standard tuned transformer system only in the immediate grid circuit. This condition accentuates oscillation tendencies, so the elaborate shielding construction must usually be employed when the set layout is very compact, and wiring very carefully done to prevent coupling between stages and coupling between the input and output of any one stage. This is best accomplished by surrounding the grid coils, condensers, and other parts with grounded metal shields of copper or heavy aluminum. The shielding is further aided by keeping the lead from the control grid as short and direct as possible, and surrounding it by a grounded metal sheath if necessary. It is possible to purchase shielded control grid lead and tube shielding jackets complete as units.

The amount of shielding necessary will depend upon the voltage amplification per stage and the circuit and mechanical design of the set. It is difficult to operate these tubes in a circuit designed to give even nearly the maximum amplification of which the tube is capable without trouble due to instability, because any slight amount of feed-back is amplified tremendously by the high mu of the tubes. Of course, the circuit can be stabilized by any of the "losser" methods, but this results in a decrease in efficiency.

Another source of feedback is due to the fact that the various shielding grids

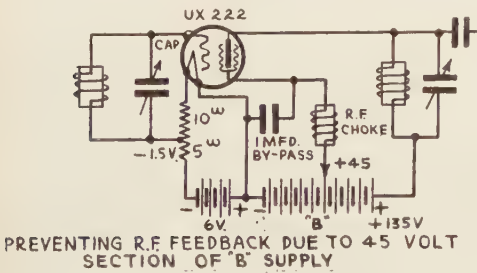


Fig. 229

in a cascade tuned system are grounded through a 45 volt tap in the common B circuit. Since the radio frequency voltage variations on the control grids of the tubes produce not only plate current variations in the main plate circuits, but also similar smaller variations in the screen-grid circuits (see Fig. 222A), it follows that this 45 volt section which has some impedance may act as a coupling agent, producing feedback between the stages. This can be prevented as shown in Fig. 229 by inserting a radio frequency choke coil in series with each 45 volt lead, with

the high potential side shunted back to the filament of the tube by a fixed condenser of from .01 to 1 mfd. capacity. This confines the R. F. currents in the screen-grid circuits to their own respective stages.

296. **SELECTIVITY:** The selectivity of receivers employing only one or two stages of screen-grid radio frequency amplification is usually very much poorer than those employing 201-A type tubes. This apparent loss in selectivity is partly due to the great gain in sensitivity. To make this clear, let curve A of Fig. 230 be the resonance curve of a single stage of R. F. amplification using a 201-A tube and tuned to a broadcasting station operating on say 1100 kilocycles.

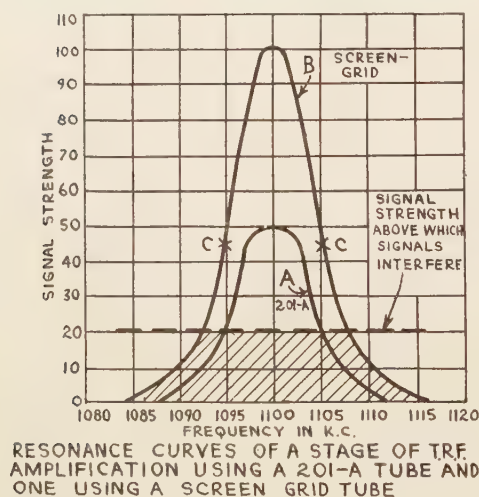


Fig. 230

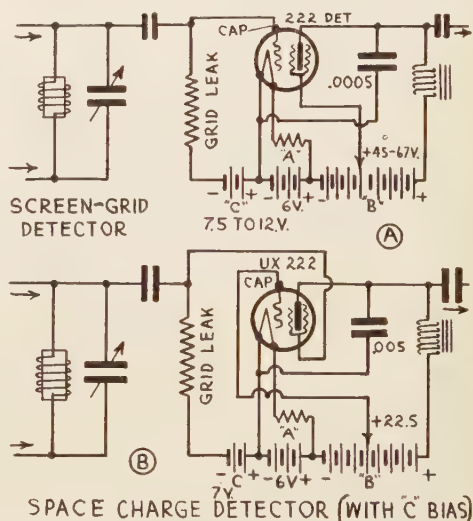


Fig. 231

Let curve B be that of a screen-grid stage tuned to the same station and in which the gain is twice as great, that is, every point of curve B is twice as high as a corresponding point on A. If local stations are separated by a 10 K. C. transmission band (10 K.C. wide), then on curve A the incoming signals of a station 5 K.C. off resonance are below the dotted line which represents the arbitrarily chosen signal strength above which interference occurs, and below which an interfering signal is too weak to be heard. Now referring to curve B of the screen-grid amplifier, it is evident that the 5 K.C. off resonance signal is at C, stronger than the signal strength above which interference occurs, and is heard in the background of the station to which the receiver is tuned. Or in other words, the increased amplification increases the strength of the unwanted signals and interfering noises as well as the wanted signals unless the selectivity is increased at the same time. It is this fact that sets a very definite limit on the amount of sensitivity desired in a receiver consistent with quiet and selective operation. The solution to this problem may lie in the proper use of a number of stages of tuned R. F. amplification in order to gain the benefits of the selectivity thus acquired, or to use a Vreeland band selector system of amplification employing two closely

coupled circuits where the resonance curve is flat topped and very steep on the sides, admitting a band of frequencies only 10 K. C. wide.

297. SPACE CHARGE GRID R. F. AMP.: Using the four electrode tube as a space charge grid tube (see Figs. 215 and 216) in an R. F. amplifier is not practical because of the large capacity which exists between the outer grid which now becomes the control grid) and the plate. This is due to the large exposed area of the outer grid and plate, and results in excessive feedback.

298. SHIELDED GRID DETECTOR: The screen-grid tube can be used as a detector. If the detector is preceded by one or more stages of screen-grid tube R. F. amplification, detection should be accomplished by the "C" bias method as shown in Fig. 231A, in order to prevent overloading of the detector. It can also be used as a space charge grid detector as shown in Fig. 231B, with the advantage of lower plate impedance for coupling to the audio amplifier. When screen-grid tubes are used as detectors, they are usually followed by a first audio stage employing resistance coupling instead of transformer coupling. This is because it is much cheaper to obtain the necessary high plate impedance necessary for good amplification by means of a resistance coupled stage than it is with a transformer coupled stage.

299. A. F. AMPLIFICATION: The screen-grid tube can be used as an audio frequency amplifier but here again the coupling unit must possess very high impedance over the audio frequency range to match the plate impedance of the tube if large gain is to be obtained. Resistance coupling is used almost entirely in screen-grid A. F. amplifiers for this reason.

300. RESISTANCE COUPLED AUDIO AMPLIFIER: The four electrode tube can be used in an audio frequency amplifier employing resistance coupling, either as a screen-grid tube (Fig. 232) or as a space charge grid tube.

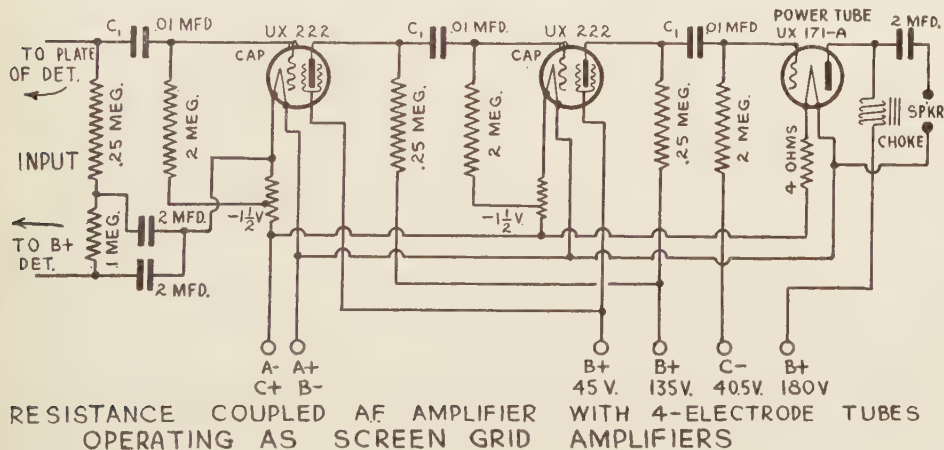


Fig. 232

Fig. 232 shows the circuit for a three stage resistance coupled amplifier employing two screen-grid tubes and a power output tube. The excellent amplifica-

tion curve of this amplifier is given in Fig. 233 together with curves for other combinations of tubes for comparison. The frequency response obtained with this amplifier is practically flat from 100 to 10,000 cycles. At the higher frequencies the tube capacities shunt the plate resistors with consequent loss of amplification. Of course, the response of this amplifier is really better than it need be, for frequencies above about 6,000 cycles do not contribute very much to the naturalness of reproduction and as a matter of fact an amplifier which cuts-off at about 6,000 or 7,000 cycles is less noisy.

The tremendous amplification of 22,000 makes the construction and prac-

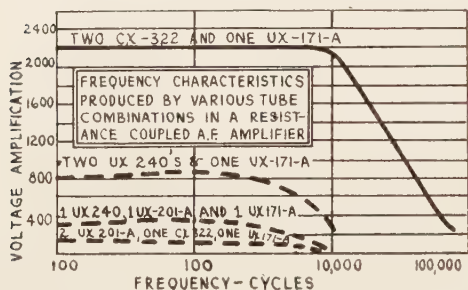


Fig. 233

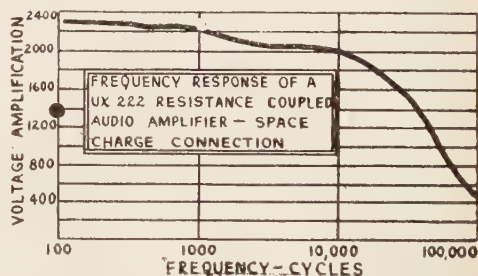


Fig. 234

tical use of such an amplifier difficult if tube noises, instability, electrical disturbances, etc., are to be avoided. (The voltage gain of an average two stage transformer coupled amplifier is about 250.) Assuming that the 171-A power tube contributes a voltage amplification of 3, the two screen-grid tubes contribute about 27 each. The 0.1 megohm resistor and two 2 mfd. condensers in the detector plate circuit tend to prevent the amplifier from motorboating.

The frequency response of an amplifier of this type depends on several factors including the voltages at which the screen-grid tubes are operated. The low frequency response is decreased as the capacity of coupling condenser C is decreased. The high frequency response decreases as the values of coupling resistance is increased, because under such conditions the input and output capacities of the tubes form a more effective shunt around the resistors.

While the four electrode tube used as a space charge grid tube in a resistance coupled audio amplifier possesses advantages due to lowered plate impedance, there is a disadvantage due to the appreciable decrease of amplification at the higher audio frequencies. This can be seen from the response curve in Fig. 234 of an amplifier of this type employing the same circuit constants as in Fig. 232 with the exception that the tubes were used with space charge connection. The large tube capacities existing with space charge grid connection shunt the resistors as mentioned above. Reproduction from such an amplifier would be very poor, unless used with a loud speaker giving exaggerated response at the high audio frequencies.

301. IMPEDANCE COUPLED A. F. AMPLIFIER: The excessive cost of transformer or impedance coupling units having the necessary high impedance at the low audio frequencies to effectively match the high plate impedance of

screen-grid tubes make it more practical to use the tube as a space charge grid tube for audio amplification by these methods. In this case with 222 tubes the inner grid is kept at a positive potential of about $22\frac{1}{2}$ volts and the outer grid used as the control grid, with a plate potential of about 135 volts. When used in this manner, the amplification factor is around 60, the plate impedance drops to about 150,000 ohms and the mutual conductance rises to about 400 micromhos (see Fig. 54). Under these conditions the plate impedance of the tube can be matched fairly effectively, but the chokes will be rather expensive. Fig. 235 shows the circuit for an impedance coupled audio amplifier employing one space charge grid tube, and a power tube for output. The impedance coupling units should have a high inductance in order to match the plate impedance of the tubes. The amplifier is coupled to the three electrode detector by an audio transformer. Such an amplifier can be built to give a voltage step-up of around 350.

It is possible to use the auto-transformer or Clough shunt feed method to obtain some voltage step-up in the coupling unit. However, the auto-transformer should have the portion of the winding included in the plate circuit, of very high impedance. Special auto-transformer units are now available for this purpose.

302. TRANSFORMER COUPLED AMPLIFIER: When ordinary audio transformers are used with the four-electrode tube, the effect of a low primary inductance transformer used with an ordinary low impedance tube is obtained, that is, the amplification at both the high and low frequencies falls off, leaving a small range over which amplification is high. Obviously this leads to severe distortion. A transformer coupled space charge grid tube amplifier is shown in Fig. 236 and the typical frequency response curve of a single stage of this amplifier when used with an ordinary audio transformer (insufficient primary impedance for 222 type tubes) is shown in Fig. 237.

At the present writing no transformers having high enough primary impedance for this use are obtainable on the market. The cost of such a transformer

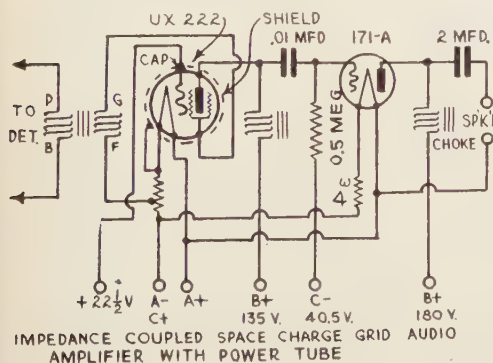


Fig. 235

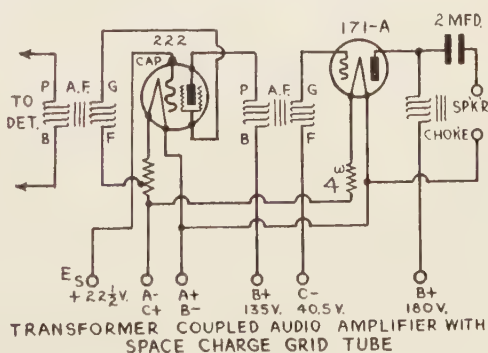


Fig. 236

would be exceedingly high. It is more advantageous to use an audio transformer with its primary and secondary interconnected (observing proper polarities for additive effect) so as to form one inductance, and to connect units of this kind

together as an impedance coupled amplifier. If the transformer is of high grade with a high primary and secondary impedance and low ratio (about 3 to 1) it can

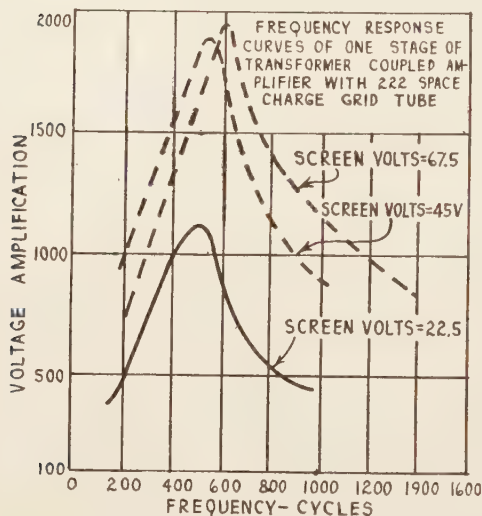


Fig. 237

coupling efficiently, affords slightly more amplification than two stages using ordinary 201-A tubes. If more than one stage of 222 amplification is used, a power output tube of large handling capacity should be employed or smaller output tubes arranged in push-pull fashion can be used.

The voltage variations on the grid of the power tube in such amplifiers may be so great with strong signals that it is usually advisable to use an impedance grid

be used as an auto-transformer by connecting the primary and secondary in series, and connecting it in the amplifier with the secondary included in the plate circuit of the space charge grid tube. Another alternative is the use of the Clough shunt feed auto-transformer system.

303. AUDIO SYSTEMS GENERAL: The use of the four electrode tube in audio amplifiers results in such tremendous amplification that overloading of the output power tube results unless proper precautions are taken. The tendency should be toward the required amount of amplification with the minimum number of tubes rather than a large number of stages producing an output which is entirely too powerful for ordinary use. One stage of 222 used with impedance

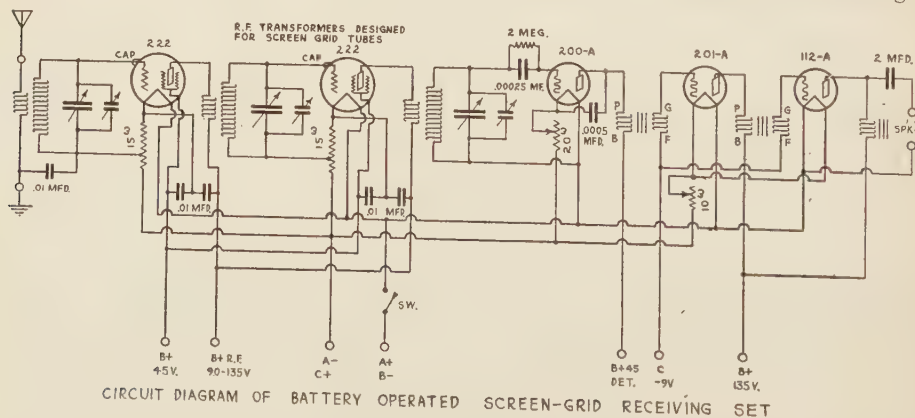


Fig. 238

leak instead of the resistance grid leak shown in the diagrams, in order to prevent blocking of the grid.

Some precaution must be taken when operating a high gain audio frequency amplifier on a socket power operated B eliminator. The amplifier will magnify any slight hum tendency. Every possible attempt should be made to eliminate any coupling impedance common to several stages by means of large capacity condensers shunted across such impedances with the possible addition of R. F. and A. F. choke coils.

Fig. 238 shows the circuit for a complete screen grid receiver containing screen-grid tuned R. F. amplification, a UX-200 A detector and audio amplification with three electrode tubes. This receiver was designed for battery operation.

304. A. C. FOUR ELECTRODE TUBES: Four electrode tubes utilizing raw alternating current for heating a conventional cathode which emits electrons are used more than the battery operated types. One form utilizes a standard 2.5 volt, 1.75 ampere heater filament. Others are designed to operate on a filament voltage of 15 volts. The A. C. type of four electrode tube (screen-grid) will be studied in greater detail in the chapters dealing with electric receivers.

REVIEW QUESTIONS.

1. Name two advantages of the four-electrode tube over the ordinary three-electrode tube.
2. What are the objectionable effects of space charge in the three-electrode tube and how does the four-electrode tube overcome them?
3. What is a screen-grid tube? What is a space-charge grid tube?
4. Draw the circuit for a single stage of R. F. amplification with a screen-grid tube, with a space-charge grid tube.
5. Why must the impedance of the load in the plate circuit of a screen-grid tube be made very high in order to obtain a high amplification?
6. Describe three coupling methods suitable for practical use in screen-grid R. F. amplifiers. What are the advantages and disadvantages of each type?
7. Why is shielding usually required in screen-grid R. F. amplifiers?
8. Why is a resistance coupled audio stage usually used following a screen-grid detector?
9. Why is resistance or autoformer coupling usually used in screen grid A. F. amplifiers in preference to transformer coupling?
10. Why is the apparent selectivity of a high gain R. F. amplifier using screen-grid tubes less than that of an amplifier with a similar number of tuned circuits, but using three-electrode tubes?

CHAPTER 18.

B-ELIMINATORS AND POWER AMPLIFIERS

BATTERY ELIMINATION—CURRENT SUPPLY—REQUIREMENTS—B-ELIMINATOR SYSTEM—POWER TRANSFORMER RECTIFIERS—HALF WAVE RECTIFIERS—FULL WAVE RECTIFIER—VOLTAGE DIVIDER—GASEOUS RECTIFIERS—FULL WAVE ELIMINATOR—CHOKES AND FILTER CONDENSERS—HIGH RESISTANCE VOLTmeter—MOTORBOATING—COMPARISON OF FILAMENT AND GASEOUS RECTIFIERS—C BIAS FROM ELIMINATORS—B ELIMINATORS AND POWER AMPLIFIERS—D. C. ELIMINATORS—B ELIMINATOR CONNECTION TO SETS.

305. **“B” BATTERY ELIMINATION:** Thus far, for the sake of simplicity in the study of the receiving set, it has been assumed that the A, B and C power for the operation of the set was supplied by batteries. However, the trend in modern set design is definitely toward the elimination of all batteries with their attendant care and renewal expense, and the complete operation of the set from the alternating or direct current electric lighting circuit. Of course, a large number of battery operated receivers will always be required for use in districts where no electric light current is available, or where for some special reason battery operation is preferred.

The complete socket power operation of a receiver requires that the current and voltage obtained from the electric light socket be made suitable for the requirements of the A, B and C supply. The problem of adapting the current to supply the B and C power requirements of the set will be studied here. The A power supply and the complete electric set will be studied in the next chapter.

306. **CURRENT SUPPLY:** Electric light current is supplied in two forms, alternating current and direct current. Alternating current is the most common and widespread. The construction of the “B” battery eliminator depends upon the kind of current supplied. The kind of current can be ascertained in any particular case by inspecting the nameplate on the electric light meter or by communicating with the local electric light company.

307. **REQUIREMENTS:** The power supplied to the B circuit of the receiver must be steady, non-fluctuating direct current. Alternating current cannot be used because the plates of the tubes must be maintained at a steady positive potential at all times. The direct current must be non-fluctuating because even a small variation in B voltage causes a change in plate current which is amplified in the set, and appears as an objectionable hum or audible note in the loudspeaker, interfering with reception. The B eliminator must be able to supply various voltages, from 180 volts or more for the modern power tubes, to 90 and 45 volts

for the amplifier and detector tubes respectively, and enough B current to operate the entire receiver. The C voltage must always be negative and, therefore, the use of alternating voltages is impossible. Steady direct voltage must be used. As any variation in potential applied to the grid of a tube shows up about six to ten times as much in the plate circuit of the same tube, due to its amplifying properties, the "C" voltage supply must also have as little fluctuation as possible.

308. B-ELIMINATOR SYSTEM: A study of the above requirements shows that a "B" battery eliminator operating from a 110-volt alternating current (A. C.) lighting circuit must do several things. It must step up the 110-volt A. C. to the higher voltages necessary for the operation of the power tube, it must rectify the alternating current, it must smooth out the resulting pulsating direct current and must provide some means for obtaining several intermediate voltages. (The D. C. eliminator will be discussed later.)

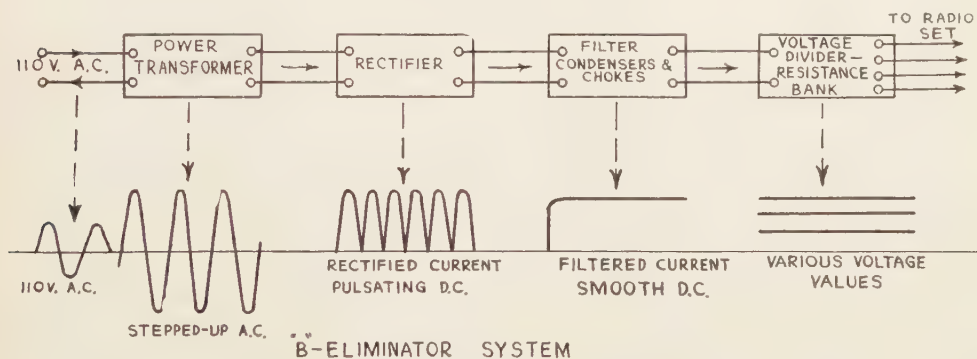


Fig. 239

These functions are performed by the various parts of the eliminator and for simplicity they will be considered separately at first as shown in Fig. 239. The 110-volt alternating current supplied by the electric light line is stepped up by a power transformer, the A. C. is changed to D. C. by a rectifier, the pulsating D. C. is changed to smooth D. C. by a filter, and various voltages are obtained by a voltage divider. (Fig. 239 shows the various sections of the eliminator and a pictorial representation of the kind of current existing in each section.) All conventional B-eliminators consist of these main parts.

309. POWER TRANSFORMER: The power or voltage step-up transformer consists of a primary and secondary coil wound on a laminated iron core. The secondary contains more turns than the primary in order to secure the voltage step-up. (See Fig. 54 for plate voltages of various rectifier tubes.) When a filament type rectifier is employed, another secondary winding of a few turns is put on for supplying the filament current for the rectifier. (See Fig. 54 for filament voltages of various rectifier tubes.) The transformer should be designed with ample copper and iron so that the secondary voltages remain practically constant even though the electric light line voltage varies slightly at different times.

310. **RECTIFIERS:** Two popular types of rectifiers are used extensively in B battery eliminators, namely, the filament type and the gaseous type. The former will be considered first. The function of the rectifier is to change alternating current to direct current. When an alternating voltage is applied to it, it allows the current to flow in one direction only, by offering a very high resistance to the flow of current in the opposite direction. Rectifiers are divided into two types, half wave and full wave. In half wave rectification, only one part of the current wave is utilized, the flow of current being stopped during each half cycle. In full wave rectification the circuit is so arranged that both halves of the wave are utilized. Two half wave tubes can be connected to form a full wave rectifier.

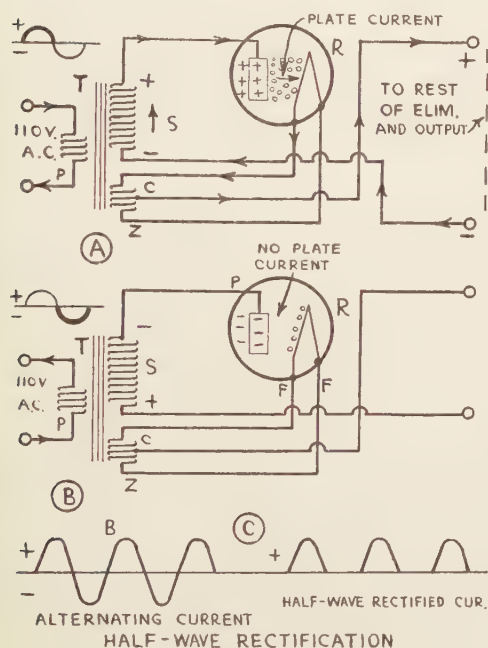
311. **HALF WAVE RECTIFIER:** A half wave rectifier tube of the filament type consists of a heated filament and a plate or anode (two electrode tube) as shown in Fig. 240A. The filament (heavy oxide-coated type) is usually heated by alternating current supplied by the winding Z on the power transformer T. The plate voltage is supplied by the winding S. As the transformer operates on A. C. the polarity of winding S reverses during each cycle. Fig. 240A shows the conditions when the top terminal of S is positive. This makes the plate of the rectifier positive and it attracts the electrons emitted by the filament. The plate current flows from plate to filament through half of winding Z to the center-tap C and out to the rest of the eliminator and set, back through the minus terminal of the eliminator to the lower terminal of S, making a complete circuit. The direction of the current is shown by the arrows. On the next half cycle (Fig. 240B) the polarity of S reverses, the top terminal now being negative. As this is connected to the plate it makes the plate negative, thus stopping the flow of electrons and no current flows through the rectifier. This half of the wave is thus eliminated, and therefore the current flows in external circuit in one direction only. Fig. 240C shows the A. C. wave applied to the eliminator from the lighting socket, and the D. C. pulsating current at the output of the rectifier. Notice that the D. C. current stops entirely during half of each cycle, making it difficult to completely filter and smooth out a current of this type, since the frequency of the pulsations is only half as great as for a full-wave rectified current. For this reason, half-wave rectifiers are not used greatly as the increased cost of the filter system necessary for quiet operation is a disadvantage.

Since there are only three connections to a half-wave rectifier tube, the fourth prong (corresponding to the G terminal of the ordinary vacuum tube) is not connected to anything, but is merely placed on the base of the tube to help hold it firmly against the socket contacts.

312. **FULL WAVE RECTIFIER:** A full-wave filament type rectifier tube consists of a heated filament and two separate plates or anodes (Fig. 241). In Fig. 241 A, which shows the typical circuit for a full-wave rectifier, each plate is connected to one end of the plate winding S of the power transformer T. The filament is heated by A. C. from the filament winding Z. Both the plate winding and the filament winding have center taps connected to the external circuit as shown. A close study of Figs. 241 A and "B" will reveal the action of the tube.

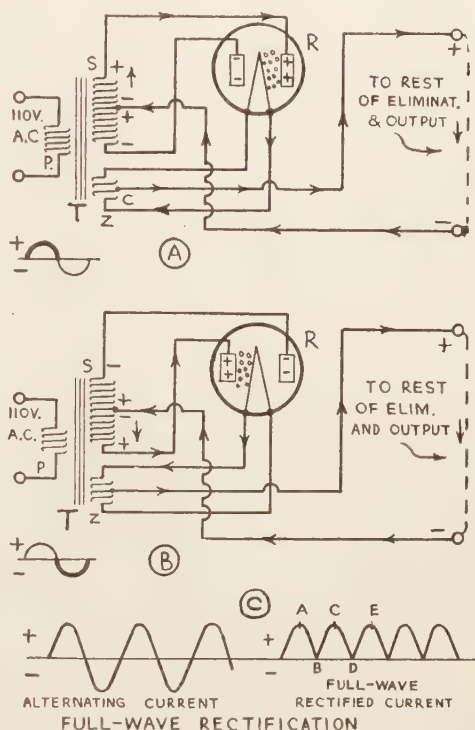
On the positive half of the A. C. cycle the upper terminal of winding S is positive, thus making the right-hand plate positive. The lower terminal of S

and the left-hand plate are negative. The center tap on S is at a potential half way between these two; it is negative with respect to the upper terminal and positive with respect to the lower terminal.) Since the right-hand plate is positive a current flows from it to the filament through half of the filament winding, as shown, and out of the center tap to the positive terminal of the eliminator, back to the negative terminal to the center tap of S. The left-hand plate, being negative, takes no part in the action. Notice that only the upper half of winding S was



Left: Fig. 240

Right: Fig. 241



effective during this period and, therefore, the effective voltage acting on the rectifier tube is half of the total voltage of winding S.

On the next half cycle Fig. 241 B the polarity of S reverses and the left-hand plate becomes positive. A current flows from this plate to the filament and around through the circuit as shown. The right-hand plate, being negative, takes no part in the action. Notice that the direction of the current in the external circuit is exactly the same as in Fig. 241 A, so the eliminator delivers a direct current.

Fig. 241 C shows the A. C. wave and the rectified current. Notice that both halves of each A. C. wave have been utilized and the rectified current is much smoother than that produced by the half-wave rectifier and therefore much easier to filter and smooth out.

313. **FILTER:** Now that we have seen how the line voltage can be stepped up and the A. C. rectified, let us study the operation of the filter which smoothes out the pulsating direct current delivered by the rectifier. Examination of Fig. 241 C shows that from A to B the current decreases and from B to C the current increases, decreasing again from C to D, etc. Any device which will keep the current constant from A to C to E, etc., will serve the purpose of filtering the current. The filters most popular at the present time consist of combinations of iron-core choke or inductance coils and large capacity fixed condensers known as filter condensers of the type shown in Fig. 141 (of Chapter 14), connected to produce the desired results. The choke coils are wound with a great many turns of wire on a laminated steel core, thus possessing high inductance and tend to oppose any change in current (Lenz's Law). The condensers store a charge of current when the current is maximum and discharge when the current decreases, thus tending to keep the current steady. Filters can be made of one or more sections, usually the completeness of the filtering increasing as the number of sections is increased. Most "B" battery eliminators employ filters of one or two sections.

Fig. 242A shows a two-section filter of the brute-force type, and a voltage divider connected to a type UX-280 full-wave rectifying tube. All voltages are shown. The successive changes in the current as it passes through the eliminator are shown in Fig. 242 B. The first condenser B can be considered as a voltage regulator in so far as it absorbs each pulsation in taking a charge off the line

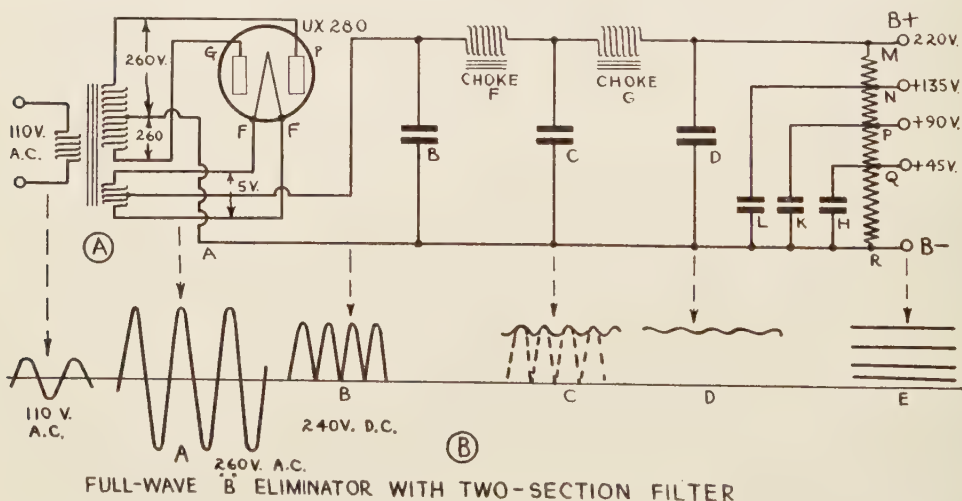


Fig. 242

and when the voltage drops, it feeds back into the line. The charge is absorbed at the peak, thus helping to fill in the valley between the peaks. The first choke coil F has a somewhat similar function, but operates in a different fashion. On account of its high inductance, 30 henries or more, it prevents rapid changes in the current passing through it. It opposes the rapid building up of the current

as it rises to a peak, by the building up of a counter-electromotive force. As the current reaches its highest value, and begins to decrease, the energy which has been stored in the magnetic field of the coil by the increasing current is now fed back into the circuit.

In the second stage C-G of the filter the same operation is carried on a second time, but the current on which it operates has had its pulsations smoothed out to a great extent on entering this stage and to a still greater extent on leaving it. The current that passes out of the second choke is usually a very smooth direct current.

The third condenser D normally floats on the line in a charged condition. If a powerful signal or a low note is amplified by the radio set, causing a heavy flow of current in the plate circuits, there is a consequent drop in voltage due to the increased IXR drop in the transformer windings, rectifier tube, etc. When such a condition arises, the last condenser having been charged at the higher potential, discharges into the line and thus meets the momentary demand for a heavier current supply. In this way the last condenser acts as a current storage device. In most cases it must be of large capacity (5 to 10 mfd.) if good low-note reproduction is to be obtained. Thus condenser B controls voltage regulation, C controls hum elimination, and D controls current storage for good quality of reproduction.

The 280 type rectifier tube can be used successfully in some circuits with a one-section filter consisting of B=4 mfd., F=30 henries, C=4 to 10 mfd.

314. **VOLTAGE DIVIDER:** If only one value of "B" voltage were required by the receiver, the B-eliminator would now be complete; but the various tubes in a receiver require different plate voltages. These intermediate values of voltages can be obtained by means of a series of fixed or variable resistors located in the circuit directly across the output terminals of the filter section.

In Fig. 242A a fixed resistance R, having taps located at predetermined positions is used to obtain the various voltages. Each section is by-passed by a 1 mfd. condenser to prevent interstage coupling through the impedance drop of the resistor. The resistances of the various sections can be calculated by

E

Ohm's law = $\frac{E}{I}$ — when the total plate current consumption of the tubes connected

I

to each tap is known. It must also be remembered that the current in the various resistor sections is different. Thus, current in section PQ is sum of current in QR and that taken from 45 volt tap. The current in NP is the sum of current in QR and current taken from 45 and 90 volt taps. This type of voltage divider is cheap and acts as a protective device against high voltage surges across the filter condensers when the external load is suddenly removed from the eliminator and the voltage rises suddenly due to the decreased IXR voltage drop. The resistance acts as a constant small load on the rectifier.

Fig. 243 shows a voltage divider employing variable resistors for producing the desired voltage drops. The resistance required for a given voltage drop is

E

calculated by Ohm's law $R = \frac{E}{I}$. Thus, if 20 milliamperes is drawn from the

I

135 volt tap, the resistance required to reduce the voltage from 180 V. to 135 volts

$$R = \frac{E}{I}$$
 when this current is flowing through it is $R = \frac{E}{I}$, or R equals 180—135 divided by 0.020 amperes (20 milliamperes), from which $R = 2250$ ohms. This method of output voltage division gives exact adjustment of voltage but is more expensive than the fixed resistor method.

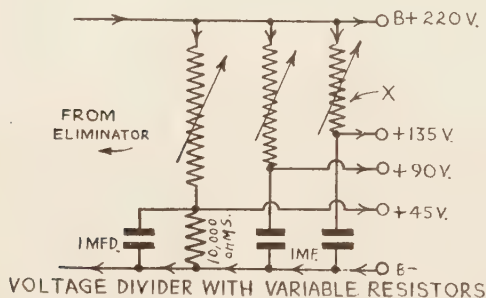


Fig. 243

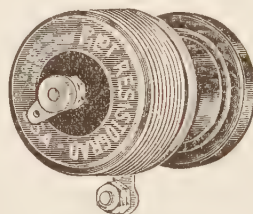


Fig. 243A. Heavy Duty Variable High Resistance for Use in Circuit of Fig. 243

Fig. 244 shows a photograph of a complete B eliminator of this type. The location of the various parts is clearly shown.

315. GASEOUS RECTIFIER: Gaseous rectifiers operate on the principle of the uni-directional conduction properties of gases. They have no filament, and consist of three electrodes, one large (cathode) and two small (anodes) enclosed in a glass bulb containing helium gas at a low pressure. The high potential impressed on the two small electrodes ionizes the gas and makes it a conductor. It conducts in one direction, from the small to the large electrode, each small electrode functioning in turn on half of the A.C. cycle. Rectification occurs due to the fact that on the reverse alternation clouds of electrons attempt to bombard the small anodes and build up a space charge which effectively blocks the flow of current in that direction. On the forward alternation, the cathode being large,

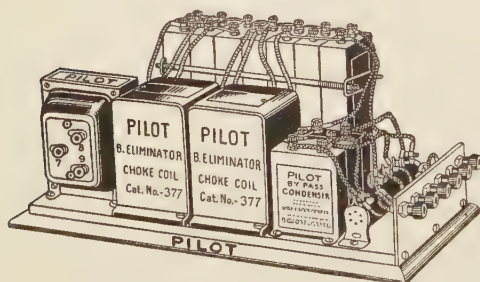


Fig. 244—B Eliminator For Use With 280 Type Full Wave Rectifier

the electrons have a large surface to strike and consequently low resistance is offered to current flow. Helium gas is used because of its low density and comparatively light mass of its atoms and ions. Raytheon tubes of this type are made in various sizes, the popular one for B-eliminators is known as type BH and is rated at 125 milliamperes capacity at a voltage of 220 volts.

Fig. 245 shows the circuit for a B-eliminator employing a Raytheon BH full wave rectifier. An actual eliminator of this type is shown in the photograph of Fig. 244. The tube is equipped with a standard UX base having four prongs.

Since there are only three connections to it, the fourth prong (corresponding to the G terminal of the ordinary vacuum tube) is not connected to anything. You will notice that a two section filter is used. This is recommended with this type of rectifier. Notice that two 0.1 mfd. buffer condensers (usually built together in a common case) are connected across the sections of the secondary winding of the power transformer. These prevent surges in the current which might cause a change in the character of the current supplied to the tube or damage to the transformer and tube. They are unnecessary when using a filament type rectifier.

Any of the voltage divider systems can be used with this type of eliminator.

316. FULL WAVE ELIMINATOR: Fig. 246 shows the circuit for a full wave eliminator using two half wave filament type rectifying tubes. The current and voltage rating of the eliminator is the same as that of one of the tubes. This type of eliminator is used where high output voltages are desired and large current drains are encountered. See Fig. 54.

317. CHOKES AND FILTER CONDENSERS: The filter condensers used in eliminators must be built to withstand the *peak* voltages encountered. The condenser nearest the rectifier is subjected to the highest peak voltages. As the voltages at the input of the rectifier and immediately following it are alternating

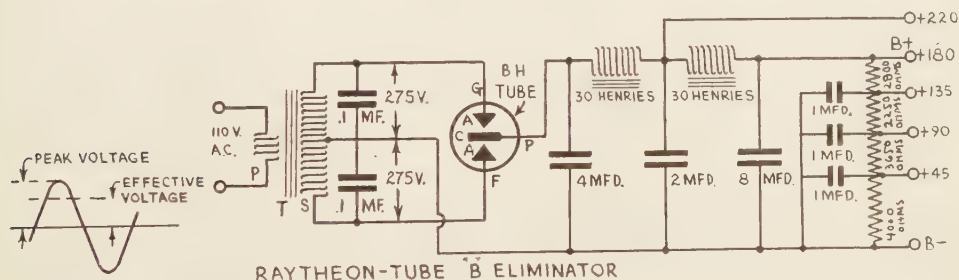


Fig. 245

and pulsating direct current voltages respectively, the values indicated are the "effective values." The "effective voltage" is the value of voltage which gives exactly the same heating effect as a direct current of the same potential. The peak value of an alternating voltage is the maximum value to which the voltage rises during any part of the cycle (see Fig. 245). The shape of the ordinary A.C. voltages encountered is such that the potential is proportional to the sine of an angle (sine wave), and when the voltage has such a form, the peak value is 1.41 times the effective voltage. As the condenser insulation must safely withstand the peak voltage twice during each cycle, the condensers used must have a voltage rating exceeding the peak voltage.

Thus, in Fig. 245 the A.C. voltage applied to the buffer condenser is 275 volts. The normal peak value (which the condenser must safely withstand) is 275×1.41 or 388 volts. This should be remembered when constructing an eliminator. The chokes should have sufficient current carrying rating, so that at no time is the carrying capacity reached. When the current rating of a choke is exceeded its induc-

tance rapidly decreases, as explained in a previous chapter, and does not then measure up to the requirements of a satisfactory choke. The D.C. resistance of the chokes should be low, to prevent excessive voltage drop through them. In Fig. 245 a 220 V. tap is taken off before the last choke. This is often done to supply a higher voltage to the last power tube since the voltage drop through the last choke is eliminated. Not as much filtering is required for this tube since any slight hum introduced is not amplified by any succeeding tubes. Also any coupling

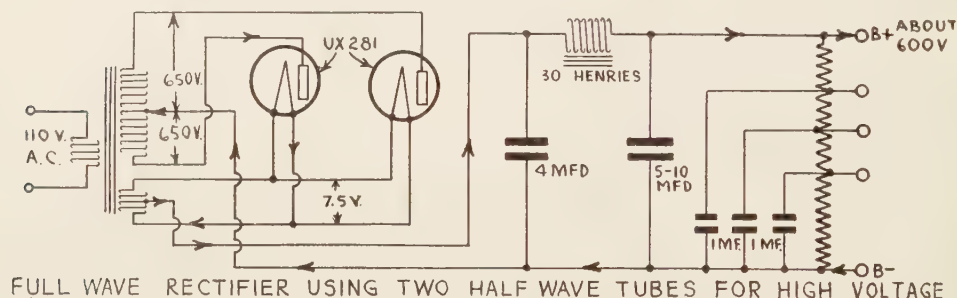


Fig. 246

which might exist between the last audio stage and other tubes in the set due to the common heavy plate current flowing through the impedance of the chokes is reduced, as the last choke is put out of the plate circuit of the power tube by this method.

It must be remembered that high voltages are present in "B" battery eliminators and proper insulation and wiring precautions must be observed.

318. **HIGH RESISTANCE VOLTMETER:** Voltage readings on a "B" battery eliminator should be made only with a special high resistance voltmeter whose resistance is at least 100,000 ohms with a full scale deflection of 200 or 250 volts. Such a meter draws very little current. The ordinary inexpensive voltmeter of the low-resistance type requires considerable current for its operation, and in a B-power unit the considerable current drain imposed by such a voltmeter causes a drop in voltage, so that it is impossible to secure an accurate voltage reading.

319. **MOTOR-BOATING:** Motor-boating in a set operated by a B-eliminator can usually be cured by one of the methods described in Article 232 of Chapter 15.

320. **COMPARISON OF FILAMENT AND GASEOUS TYPES:** Both the filament and gaseous type rectifiers are used extensively in "B" battery eliminators. An advantage of the filament type is that the buffer condensers are not necessary and only a single section filter is usually required. A disadvantage is that the tubes require renewal. The gaseous type requires a two section filter and buffer condenser but has a very long useful life.

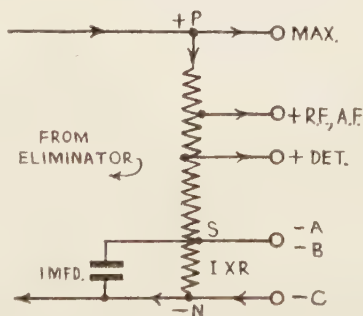
321 **C BIAS FROM ELIMINATORS:** In the usual eliminator, a nominal value of C bias can be obtained, as shown in Fig. 247 by connecting the B minus eliminator terminal to the A minus terminal at some point *above* the most

negative point of the eliminator. In the figure N is the most negative point of the eliminator, P is the most positive while S is a connection point for — A and there are taps shown for various B voltages for the set. If point N is then taken for negative C, the actual drop in voltage between S and N depends upon the current flow through the resistor between S and N. This current is the entire eliminator output and depends on the current taken by the set. The C voltage between S and N is equal to $I \times R$. A 1 mfd. condenser should be shunted across S and N to present a low impedance path for the varying plate currents, to prevent interstage coupling.

If a power tube is used in the last audio stage of a receiver, its filament can be operated by alternating current supplied from an extra winding provided on the power transformer of the B-eliminator. This is possible because the slight amount of hum introduced by the use of the A.C. is not amplified by any succeeding tubes, and is not usually noticeable. The C bias for the power tube (a 171-A tube in this case) can be secured by connecting a resistance R as shown in Fig. 248 from the center tap of the filament winding of the power tube to the B-terminal of the eliminator. The grid return of the power tube goes to the B-terminal. This is a better method than that shown in Fig. 247, and should be used whenever possible. The plate current of the power tube (shown by the arrows) flows through the filament to the five volt filament winding, out of the center tap through R to the B-terminal and around through the eliminator. Since there is an $I \times R$ voltage drop in R the potential of the grid return lead of the power tube is lower than that of the filament, i.e., a "C" bias is put on the grid. The plate current taken by a 171-A tube with plate potential of 180 volts is 20 milliamps (see Fig. 54). Therefore:

$$I \times R \text{ equals } \frac{20}{1000} \times 2250 = 45 \text{ volts}$$

which is about the recommended "C" bias voltage for this tube. Similarly the resistance R necessary to obtain a certain "C" bias for any other tube can be computed. For a UX-245 tube a resistance of 1350 ohms should be used when a plate voltage of 180 volts is employed. When 250 volts are applied to the plate, a 1600 ohm "C" bias resistor should be employed to give correct "C" bias voltage.



OBTAINING "C" BIAS FROM "B" ELIMINATOR

Fig. 247

322. "B" ELIMINATOR AND POWER AMPLIFIER: The introduction of power tubes for use in the last stage of the audio frequency amplifier has made "B" battery eliminators a necessity on account of the high plate voltages and current drain necessary for these tubes. Dry "B" batteries would not last very long when operated with these sets. It has become common to construct the "B" battery eliminator and last stage or both stages of audio amplification together in one unit. This simplifies much of the wiring and results in a unit which has

many uses. Fig. 248 shows the circuit for a "B" eliminator and power amplifier unit employing a UX-280 full wave rectifier and a 171-A power tube. The circuit diagram for a power amplifier and "B" eliminator for use with a 250 type power tube is shown in Fig. 249.

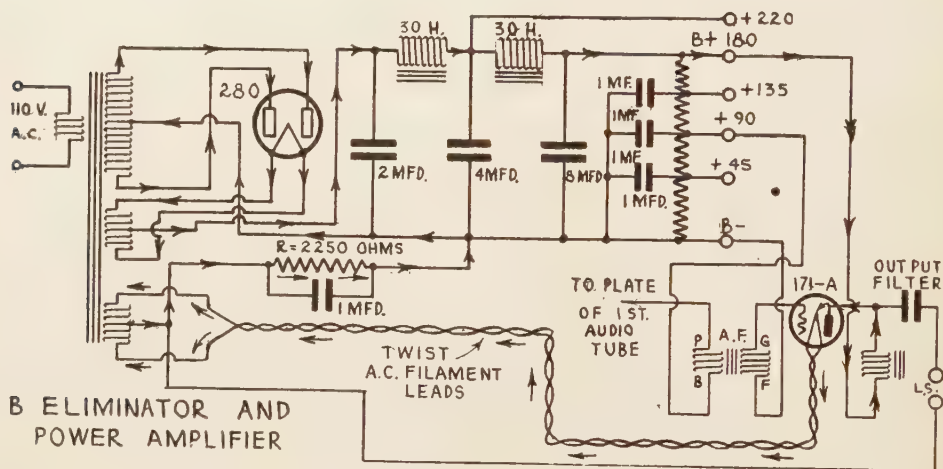


Fig. 248

Fig. 250 shows a compact power amplifier and "B" supply unit built on an aluminum chassis.

The first amplifier tube, a 227, is not accompanied by any coupling device,

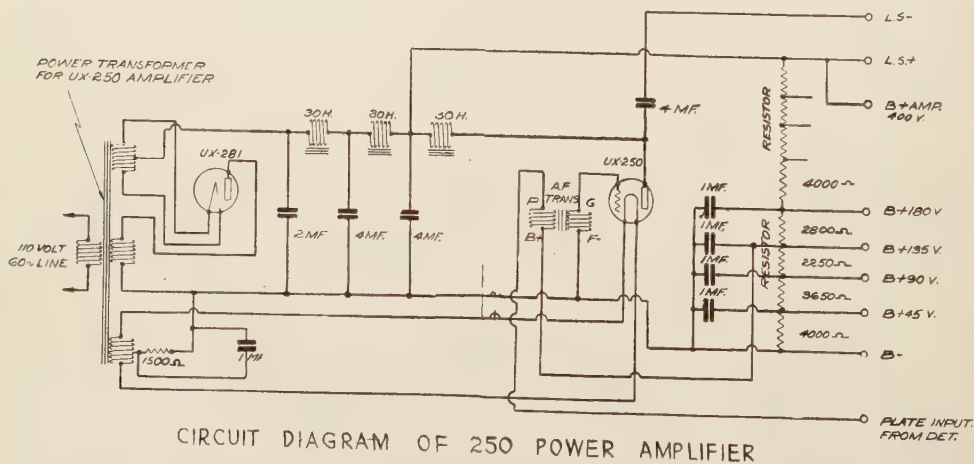
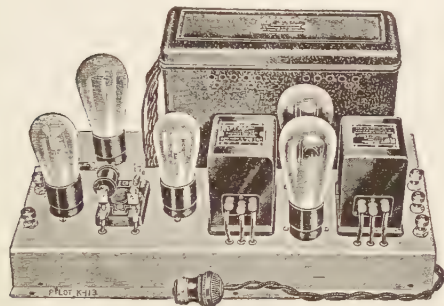


Fig. 249

the choice of the input system being left to the constructor. If the amplifier is to be used for public address work, the microphone modulation transformer is con-

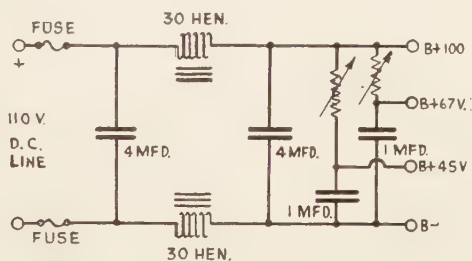
nected to this tube. The first transformer may also be used in conjunction with a radio receiver.

The first tube is resistance coupled to the second, which is also a 227, and this in turn works into a push-pull stage using 245 tubes. The output transformer is



Left: Fig. 250. Power Amplifier With Power Pack. Includes one stage resist coupled audio, one stage transformer coupled with 227 tube, and one 245 push-pull stage.

Right: Fig. 251.



CIRCUIT OF B-ELIMINATOR FOR D.C.

a special instrument with a tapped secondary giving output impedances of 1500, 2500 and 4000 ohms, respectively. The amplifier may thus be matched to any speaker or combination of speakers; it will handle two large dynamics or from three to five magnetic speakers. The unit is completely self-contained, all "A," "B" and "C" voltages being supplied by the power pack.

323. D. C. "B" ELIMINATOR: A "B" battery eliminator for operation from the 110 volt direct current lighting circuit is a very simple device, since it requires no rectifier. As the direct current supplied by the electric light company contains slight pulsations due to the coils and commutator employed on the D.C. generators, the current must be filtered slightly. However, it is impossible to step up the voltages as is done with the A.C. types of B-eliminators as direct current cannot be stepped up in voltage. Therefore if power tubes are to be used when only 110 volts D.C. is available, they can be connected in parallel or in push-pull to secure greater handling capacity with low plate voltage, or a block of "B" batteries can be connected in series with the output of the B-eliminator.

Fig. 251 shows a B-eliminator for use on D.C. lighting circuits. When used with some sets it is possible to leave out one of the 30 H. filter chokes. When using eliminators on D.C. circuits it is always advisable to insert a 1 mfd. condenser in series with the ground lead of the receiver. This allows the R.F. signal to pass through freely but blocks the passage of the 110 volt direct current which would cause a short circuit if the line terminals of the eliminator were accidentally reversed. The choke coils used in the eliminator should be of low resistance, to prevent excessive voltage drop. The eliminator can be built as a unit with the last audio power stage as in the case of A.C. eliminators.

In some installations where a three wire system feeds the D.C. lighting circuit it is possible to obtain 220 volts for the eliminator by connecting to the two outside wires of the three wire line.

323. **B-ELIMINATOR CONNECTION TO SETS:** The connection of B-eliminators to receivers will be studied in the next chapter.

REVIEW QUESTIONS

1. State several advantages of operation of a receiver with a "B" eliminator over operation with "B" batteries.
2. Why can't alternating current be used directly on the plates of vacuum tubes in a receiver?
3. Name four principle parts of a "B" eliminator and describe the function of each.
4. Describe the action of the half-wave rectifier.
5. Describe the action of the full-wave type and state its advantages over the half-wave type.
6. Describe the action of an ordinary choke coil-condenser filter system of the brute-force type. What is the function of the choke coils; the filter condensers?
7. Describe the function of the voltage divider. Draw circuit diagrams for two types and state the advantages and disadvantages of each.
8. Describe briefly the principle of operation of the gaseous type (Raytheon) of full-wave rectifier.
9. Why must the filter condensers in an eliminator be designed to withstand the "peak" voltages? Which condenser in a two section filter is called upon to withstand the highest voltages? Why?
10. Why should a high resistance voltmeter be used for all voltage measurements on "B" eliminators?
11. How can "C" bias voltages be obtained from a "B" eliminator?
12. Draw a circuit diagram for a "B" eliminator designed to operate from the 110 volt D.C. line. Why is it impossible to obtain more than 110 volts from this type of eliminator?

CHAPTER 19

ELECTRIC RECEIVERS

GENERAL CONSIDERATIONS—PARALLEL VS. SERIES FILAMENTS—STUDY OF SERIES CONNECTION—LAST AUDIO TUBE—INTERSTAGE COUPLING—COMPLETE SERIES FILAMENT RECEIVER—POWER UNIT—A.C. TUBES—D.C. ELECTRIC SET—HEATER TYPE TUBES—FILAMENT SUPPLY—HUM CHARACTERISTICS—GRID BIAS AND VOLUME CONTROL—COMPLETE A.C. TUBE SET—A.C. TYPE OF FOUR ELECTRODE TUBE—HUM CHARACTERISTICS OF 224 TUBES—A.C. SCREEN-GRID ELECTRIC RECEIVER—HUM IN ELECTRIC RECEIVERS.

324. **GENERAL CONSIDERATIONS:** In Chap. 18 various types of practical "B" eliminators, for supplying unvarying, smooth direct current to the B circuits of receiving sets were described. These take their power from the A.C. light socket. A "B" eliminator is an essential part of any receiving set which is to derive its power from the electric lighting socket. The problem of supplying the "A" current for the filaments of the tubes from the A.C. light socket is somewhat more difficult, and has been solved in two general ways, i.e., by series filament connections in conjunction with a heavy duty rectifier, and by the use of special A.C. vacuum tubes using raw A.C. on the filaments. The latter method is the most practical and is the basis of most electric receivers used at the present time.

Before proceeding further with the subject of electric receivers it will be well to become familiar with the nomenclature which has originated in this connection. It is obvious that various combinations of electrical operation methods can be resorted to in any set. Thus a set may use a "B" battery eliminator but use a storage "A" battery for filament supply. Such a set is not a true electrically operated receiver.

The following standard definitions adopted by the Radio Manufacturers Association will be used in this book.

(1) "Battery-Operated Set":

A radio receiver designed to operate from primary and (or) storage batteries.

(2) "Socket-Powered Set":

A radio receiver of the battery-operated type when connected to a power unit operating from the electric light line, supplying both filament and plate potentials to the tubes of a receiver.

(3) "Electric Set":

A radio receiver operating from the electric light line without using batteries.

(4) "A.C. Tube Electric Set":

A radio receiver employing tubes which obtain their filament or heater currents from an A.C. electric light line without the use of rectifying devices, and with a built-in rectifier for the plate and grid-biasing potentials.

(5) "D.C. Tube Electric Set":

A radio receiver employing tubes which obtain their filament or heater currents from a direct current electric light line, without the use of rectifying devices and with a built-in power supply for the plate and grid biasing potentials.

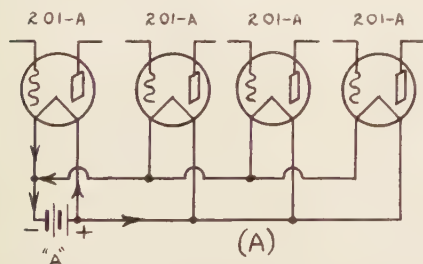
Ordinary 201-A type tubes produce a hum when operated on alternating current because of the slender filament carrying the current. In ordinary 60 cycle current the current varies from zero to its maximum value twice for each cycle or 120 times a second. The slender filament is sufficiently sensitive to these current changes to vary its heat in step with these variations in the heating current. This change in heat of the filament causes a change in plate current. This is carried on through the various stages and is amplified, making itself evident in the loud-speaker as an objectionable 120 cycle hum which ruins reception. A certain amount of hum is also due to the capacity effect between the tube elements, and to the voltage drop along the filament. Another appreciable source of hum is due to the fact that if an alternating electro-motive force is applied to the ordinary tube filament it causes a periodic variation of the potential of the grid and plate with reference to the center of the filament. This is due to the fact that on one half cycle the left side of the filament is positive and on the next half cycle the left side is negative. Thus the grid and plate voltages are increased and decreased by a voltage equal to half the filament voltage, twice for each cycle. Thus variation of plate and grid potential causes a corresponding variation in plate current at twice the frequency of the supply voltage. For the ordinary 60 cycle electric light supply, a 120 cycle hum results from this action.

Alternating current can be used on the filament of the last audio tube however, as explained in the previous chapter, because no amplifying tubes follow it. Also as most modern power tubes use a thick ribbon oxide coated filament the heating and electron emission are practically uniform.

325. PARALLEL VS. SERIES FILAMENT CONNECTION: One possible way to furnish the direct current for the heating of the filaments of 201-A tubes is to employ a rectifier and filter system similar to that used in "B" eliminators. This is impractical with the filaments connected in the ordinary way (parallel) because of the difficulty of rectifying and filtering the heavy currents needed (1 to 2 amps.) at low voltages (5 volts). The choke coils necessary for such heavy current circuits must be of such large physical dimensions as to be impractical for sets of reasonable cost. Also the effectiveness of the filter condensers decreases enormously as the voltage is decreased. A filter condenser is about 1600 times more effective at 200 volts than at 5 volts, which means that the condenser on the 5 volt circuit, for equal electrical effectiveness must have 1600 times the capacity of the one on the 200 volt circuit. This is because the energy stored in a condenser increases as the *square* of the voltage (energy of the charge equals $\frac{1}{2} CE^2$, where C is capacity and E is the voltage). Electrolytic filter condensers of large capacity may be used on sets of this type.

Consideration of these factors shows why it is impractical to operate a set containing 201-A type tubes with filaments in parallel, from a conventional rectifier and filter system from an A.C. supply line. However, the filaments can be connected in series (Fig. 252B) instead of in parallel Fig. 252A. Parallel connection of filaments has been used so long that there is a general impression that they must be connected that way. This is not so. Series connection of filaments has been common in telephone work and in U. S. Signal Corps receivers for years. The parallel connection became popular in the early days of radio because the popular six volt storage battery was selected as the logical filament current supply for the 5 volt tubes at the time. This necessitated a parallel filament connection if more than one tube was to be operated from a single battery.

When filaments are connected in parallel, the supply voltage must be the voltage that one tube requires (5 volts for a 201-A tube) and the total current is the sum of that taken by each tube, Fig. 252A. The total power supplied is equal to the product of the terminal voltage and the total current. When the tubes are in series, Fig. 252B, the supply voltage must be the sum of the terminal voltages of all the tubes, and the total current is that taken by one of the tubes. The total power supplied is the same as for the parallel connection.

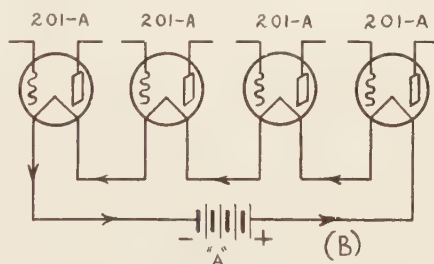


PARALLEL CONNECTION OF FILAMENTS

$$\text{TOTAL CURRENT} = 4 \times 0.25 = 1 \text{ AMP}$$

$$\text{TOTAL VOLTAGE} = 5 \text{ VOLTS}$$

$$\text{TOTAL WATTS} = EX1 = 5 \times 1 = 5 \text{ WATTS}$$



SERIES CONNECTION OF FILAMENTS

$$\text{TOTAL CURRENT} = 0.25 \text{ AMPS.}$$

$$\text{TOTAL VOLTAGE} = 4 \times 5 = 20 \text{ VOLTS}$$

$$\text{TOTAL WATTS} = 20 \times 0.25 = 5 \text{ WATTS}$$

PARALLEL AND SERIES CONNECTIONS OF FILAMENTS

Fig. 252

There are two main reasons why the series filament connection is so much more desirable for the operation of filaments on direct current from a rectifier and filter. The first is that the total current to be rectified and filtered is very much less than with the parallel connection, making the rectifier and filter system cheaper. The second reason is that currents of higher voltages are to be filtered, making the filtering efficiency of a filter circuit having given sizes of chokes and condensers much greater.

Full wave rectifiers of the gaseous conduction type, having a current capacity of 350 milliamperes at 200 volts are available for operating series filament connected receivers from the A.C. light socket. As the filaments of 201-A type tubes require 0.25 amp. or 250 milliamperes, this leaves 100 milliamperes for B current, which is more than ample. The 201-B type tube, which draws a filament

current of 125 milliamperes (0.125 amperes) at 5 volts, and has the same characteristics as the 201-A type is also suitable for operation by this method. These tubes are not in general distribution however.

Series operation of 199 type tubes (0.06 amp. or 60 milliamperes filament current) with a 125 milliampere rectifier tube and filter system has been used satisfactorily, except for the fact that the 199 type tubes are not very rugged and must be carefully handled. The tube filaments are easily damaged by slight overloads due to increases in line voltage.

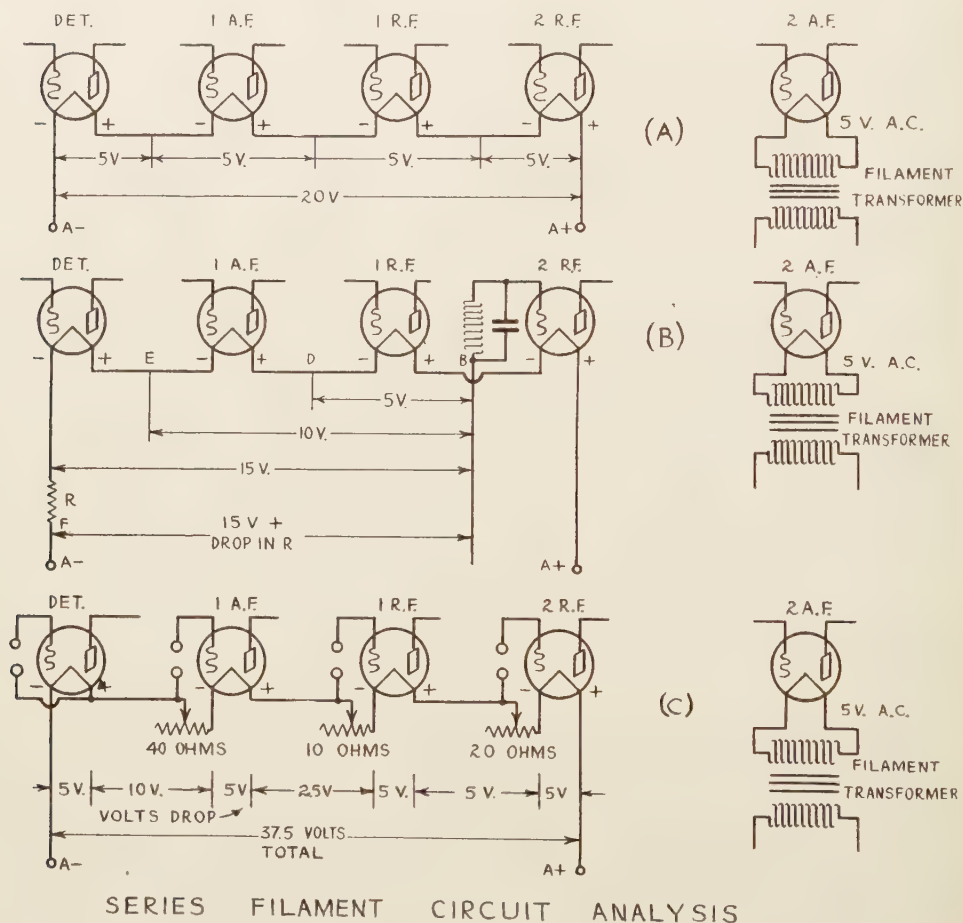


Fig. 253

326. STUDY OF SERIES CONNECTION: The sequence in which the tubes are placed in a series connected receiver is important. It has been found that less difficulty with hum is experienced if the detector is placed nearest the B minus or ground connection, followed by the next most sensitive tube, and so on. The order can be, det., 1st A.F., 1st R.F., 2nd R.F., with the 2nd A.F. tube energized by a separate source of raw alternating current from the power transformer,

as in Fig. 253A. It is necessary to maintain the grids of amplifying tubes at a negative potential with reference to the negative end of their filaments. This potential depends upon the plate potential used and the characteristics of the tube (see Fig. 54). The negative grid bias potential can be obtained in a series filament circuit by utilizing the voltage drop across a resistance. This resistance may be the filament of the tubes or a separate resistor connected in the circuit.

In Fig. 253A four 201-A type tubes are shown connected in series. There is a voltage drop of 5 volts across the filament terminals of each tube due to the resistance of the filament. The total voltage of 20 volts then drops in 5 volt steps, taken from the A + terminal. This voltage drop can be used as a negative bias for amplifier tubes. It is only necessary to connect the grid return of amplifier tube in question to the place along the line where the voltage (with respect to the negative side of the filament of this tube) is that required for proper bias. For example, in Fig. 253B, the grid return of the second R.F. tube, if returned to point B would have no bias with respect to the negative end of its filament. If it were returned to point D (the negative end of the preceding tube) it would receive a negative grid bias of 5 volts, since the potential falls 5 volts from B to D. The figures indicate the negative biases resulting from connection to the other possible return points. If a bias greater than that provided by the drop across the filaments were desired, it could be secured by inserting a resistor R in series with the line as indicated. Grid biases for the other tubes can be worked out in the same way.

Multiples of five would seldom prove satisfactory for grid biasing, so it is usually necessary to provide some means where intermediate voltages can be secured. If a fixed biasing voltage is desired, a fixed resistor of the proper value

E
I

($R = \frac{E}{I}$) can be inserted between the negative filament terminal of the tube and

grid return. If the grid bias is to be adjustable, a variable resistance can be used as in Fig. 253C. For 201-A tubes an ordinary 20 ohm rheostat can be used, and will give a variable grid bias from 0 to 5 volts. The grid bias secured by any resistance is equal to the product of the resistance in ohms by the filament current in amperes. ($E = I \times R$.)

When additional resistance is placed in the series circuit, to provide grid bias, the voltage drop over these resistances must be added to the total voltage supplied to the filaments. To test for the correct supply voltage a D.C. ammeter or milliammeter can be connected in the series circuit and the voltage from the eliminator adjusted until the instrument reading is the proper one for the tubes used. It is advisable to incorporate by-pass condensers of about 1 mfd. across these resistances.

327. LAST AUDIO TUBE: By using raw A.C. on the filament of the last audio tube, better performance is obtained. This is due to the fact that the potential difference between the filament circuit of the power tube and the filament circuits of the remaining tubes can be made equal to the grid bias required for the last tube (40 volts or so) and thus as shown in Fig. 254 the grid voltage is obtained without the introduction of undesirable interstage coupling which would result if this voltage drop were to be obtained by passing the return plate current of all the tubes through a common resistor.

A study of Fig. 253A shows that the plate current of each tube must return

The use of single control tuning with attendant use of ganged condensers with common rotor circuits presents several problems when incorporated in series filament receivers. This is due to the methods of obtaining the C bias voltages.

329. COMPLETE SERIES FILAMENT RECEIVER: Fig. 254 shows the complete wiring diagram for a six tube receiver and power unit using a 350 milliampere gaseous rectifier and 201-A type tubes with filaments in series. A four gang condenser provides single control tuning.

As the rotors of all the tuning condensers are common to each other, the shaft must be grounded to some common point in the filament circuit. Instead of each grid tuning coil being connected directly to the rotor of its condenser, it must go to a point sufficiently negative with respect to its filament to secure proper grid bias. Obviously all of the grid coils cannot return to the rotor, for this would result in a different grid bias on each tube. The rotors of the condensers are connected to a common point and the grid returns of the tuning coils are returned to their correct positions for proper grid bias. To eliminate resistance losses in the tuned circuits of the first two stages (since the tuned circuits complete themselves through the filaments), by-pass condensers C1 and C2 are used. By this sequence of filament connections and circuit connection, no by-pass condenser is required for the third R.F. or detector tuned circuits. This method solves the problem of using gang condensers.

Reference to Fig. 254 shows that the power unit is similar in many respects to the conventional gaseous rectifier type "B" eliminator. The chokes and power transformer are necessarily larger, as heavier currents are handled. The voltage dividing system can consist either of fixed or variable resistors. The 4000 ohm resistor connected across the plus and minus A is a protective device which prevents undue strains on the fixed condensers in the event of the filament circuit being suddenly opened by a tube burnout, etc.

Electric receivers with filaments wired in series have not become very popular due to the many inherent difficulties in producing satisfactory sets of this type in

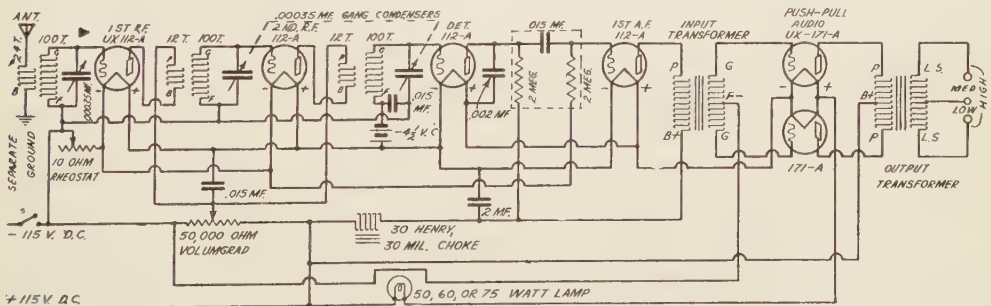


Fig. 254A—Circuit Diagram of D.C. Electric Receiver

quantity production. They have given way almost entirely to sets employing A.C. tubes.

330. D. C. ELECTRIC SET: There are some localities in which only direct current at 110 volts is available on lighting circuits. In these places the

electric radio receivers must be designed to operate from this current. The diagram of Fig. 254A shows the circuit of a receiver designed by Mr. David Grimes especially for operation from the 110 volt direct current electric light lines. This represents a practical application of series filament circuits. Here the several filaments in the various stages are connected in a series-parallel arrangement as shown in Fig. 254B. The first two R.F. stages are connected across each other. The detector and first audio tube are so connected and the last audio stage, which is a push-pull combination, has the two filaments arranged in series. Each of the three groups is connected in series with the others and with a 60 watt incandescent lamp in the positive end of the line, and a ten ohm variable rheostat in the negative end of the line.

In a set of this type it is impractical and expensive to attempt to operate all the filaments in parallel, such as is customary in a battery receiver. This would call for a current drain for the six tubes of one and one-half amperes. The series voltage-dropping lamp would have to be around 150 watts. It is obvious that this is a real load on the meter as compared with the 60 watts in the receiver discussed herewith. Furthermore, it is necessary to incorporate some additional voltage drop in the minus end of the circuit to act as the negative "C" bias for the various stages. These voltage drops might just as well be furnished by the filaments of tubes in other stages. The next natural question pertains to running all of the filaments in series for still further reduced current drain. As the filaments would only draw one-quarter ampere, the resistance lamp would only have to be of twenty-five watt size. Also, the filament voltage drops across each tube would act as the negative "C" bias for the adjacent tube located in the positive lead.

The trouble with complete series filaments is that each filament connected in series subtracts that much voltage from the total available for the plate supply. The six tubes reduce the line voltage by 30 volts—dropping the 115 volt source down to a mere 85 volts. There is absolutely no need to run any more tubes in series than that required for the maximum negative "C" bias on the power tubes. This amount of voltage has to be taken from the plate supply. The best all around compromise is that presented in Fig. 254B. By placing the power tubes at the positive end of the filament string, the filaments of the other tubes can be utilized for the negative bias. Maximum plate voltage with minimum current drain is possible with this scheme. Complete parallel operation of filaments consumes too much current in a D.C. electric receiver. Complete series operation of filaments consumes too much voltage. The series-parallel arrangement is a practical answer

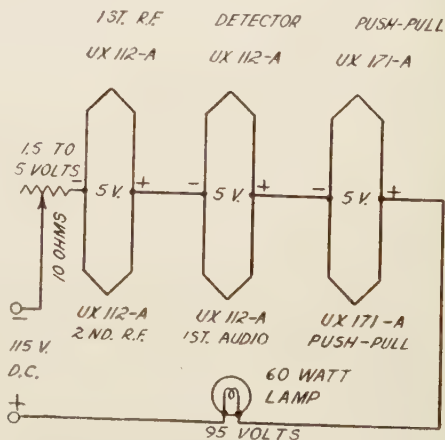


Fig. 254B. Filament Circuit of D.C. Electric Receiver

to these conditions. The correct grid bias for both the first and second R.F. stages is furnished by the 10 ohm rheostat connected in the negative filament line of these tubes. The bias may be regulated as the resistance varies the potential from zero to five volts. For best results on distance, the grid bias should be about $1\frac{1}{2}$ volts, but for best quality on loud, local stations the bias should be set at the maximum value of five volts. This is because this resistance also furnishes part of the bias for the power stage, as explained later on.

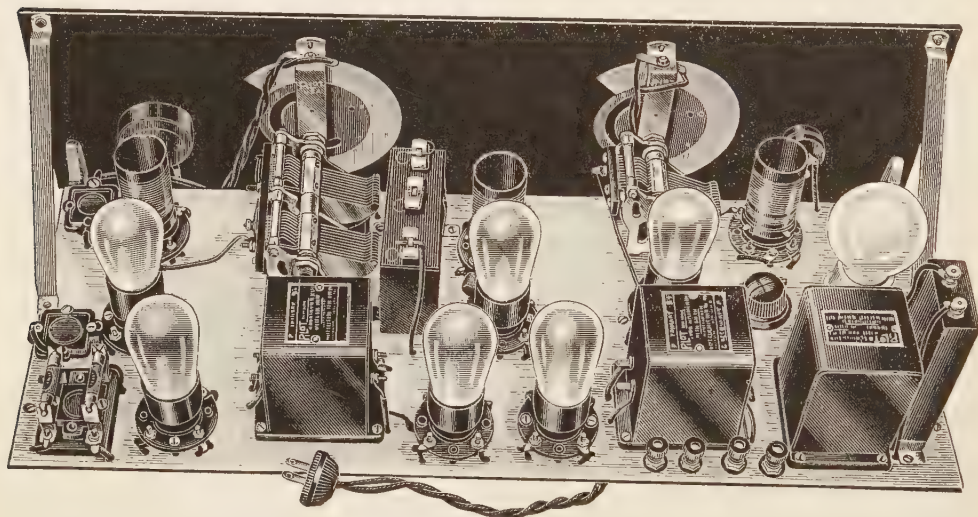
The bias solution for the detector has not been so simple. Any noise voltages in the grid of the detector are amplified many times by the succeeding audio stages. All attempts to electrify this grid bias have resulted in disappointment. Under some conditions, a bias obtained by connecting the grid return across the filaments of the R.F. stages is sufficiently free from noise to be satisfactory. This occurs in locations far removed from the D.C. power house, where the capacity of the power lines acts as a filter. Of course, a grid leak system of detection would not require a bias here as the grid is returned directly to the positive end of the filament. But a grid leak system will not handle large enough energies to properly amplify the bass notes without choking. Therefore a "C" bias detector is used. A dry "C" battery is used for this purpose. Such a battery should last for at least a year and should not be a source of annoyance. The second and third tuning condensers are ganged, which accounts for the connection running between the two rotor shafts of these units. The .015 mf. fixed condenser shown in the detector grid circuit permits this ganging without confusing the separate sources of "C" bias used on the two tubes.

The grid bias on the first audio stage is easily obtained by merely connecting the return back to the negative side of the R.F. stages. Apparently, no noise difficulties are encountered here as the amplification is not sufficient to make it noticeable. This places about five volts on this grid. The grid return from the push-pull stage is even more simple. The lead is run to the minus end of the power line circuit. This gives the voltage drop across the detector-audio combination, the R.F. stages, and the 10 ohm variable resistance.

The plate supply for the two R.F. stages is taken directly off the positive end of the power line through a potentiometer. This permits a smooth regulation of the voltage for the purpose of volume and regeneration control. The potentiometer is connected across the line. It should be about 50,000 ohms. The actual resistance of this unit is by-passed by the .015 mf. fixed condenser so that only the variation in plate potential affects the volume, rather than any loss effect caused by the resistance itself which would broaden the tuning. There is no need for a filter in the R.F. plate supply. Noises here do not seem to affect the reception. The circuit connections are shown in Fig. 254A. This diagram also shows the plate supply for the last audio push-pull stage as this requires no filter either. In this latter case, it is just a question of insufficient amplification to make any electrical disturbances noticeable. The lead is run directly back to the positive power line.

The only filtering necessary on the whole layout is that presented in Fig. 254A. Extensive tests show that it is absolutely necessary to filter the plate supply of the detector and first audio tubes. Any line noise in either of the stages receives enough amplification to make the hum objectionable. But the filter is a very simple one.

It consists of one 30 henry choke coil and a 2 mf. condenser. The choke coil may be a very inexpensive one as the current flow through it is small. Only the plate current for the first audio tube flows through it; the detector plate has very little current because of the "C" bias and the high plate resistor. A cheap filter condenser can be used also because the line voltage across it is less than 100 volts.



Courtesy Pilot Radio & Tube Corp.

Fig. 254C. Grimes D.C. New Yorker Receiver

The power lines are grounded at the power house—sometimes on one side of the line and sometimes on the other side of the line. There is no way of telling this without a test. Therefore, a separate ground connection can be used for the antenna circuit. There must be absolutely no ground connected to any other part of the circuit. This is important. Also with the D.C. receiver the plug must be inserted into the socket observing the proper polarity. Otherwise the set will not work at all, since the plate voltage will be negative instead of positive.

A rear view of the complete set is shown in the photograph of Fig. 254C.

331. A. C. TUBES: The problem of A. C. electric light socket operation of radio receivers has been solved practically by the use of special A.C. vacuum tubes which utilize raw A.C. for filament heating. A conventional "B" battery eliminator is employed for furnishing "B" power.

In the 226 type of A.C. filament tube, the design is similar to the 201-A type except for the construction of the filament which is oxide coated and short and thick, taking a greater current (1.05 amp.) than the 201-A type tube and operating at low filament voltage (1.5 volts). The thick filament retains heat longer than the 201-A type, so there is less heating and cooling as the alternating current goes through each complete cycle, thus reducing the hum produced by changing filament temperature and varying electron emission. As this filament takes a few seconds to heat up when the set is turned on, the signals do not come in immediately. As

the filament is short and straight the grid effect is decreased greatly. The low voltage across the filament also tends to reduce the hum due to grid effect.

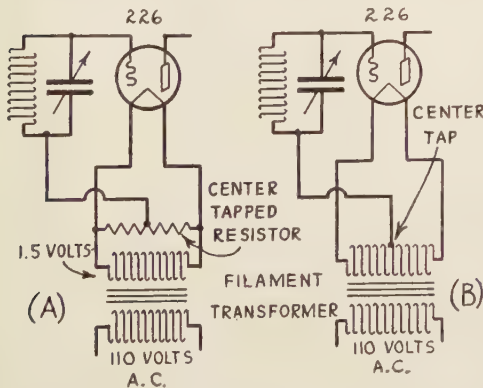
If the grid return circuit is connected to either end of the filament, the grid potential will become alternately positive and negative with respect to the midpoint of the filament (the point whose potential does not change). If it were possible to connect the grid return to the midpoint of the filament, then, of course, its potential would not change. This cannot be done, but the same result can be obtained by either of the connections shown in Fig. 255. In "A," the grid return goes to the center tap of a resistance of about 20 ohms (for 1.5 and 2.5 volt tubes) connected across the filament. In "B," the grid return goes to a center tap on the transformer winding which supplies the low voltage filament current. In both cases, the grid return is kept at the same potential as the midpoint of the filament. The potential of this point does not vary. The plate and grid circuits are returned to the center tap in either case.

The slight fluctuations in operation which do occur in the 226 type tube are sufficient to seriously affect the operation of the tube when it is used as a detector. This is the most sensitive tube in the set, as any slight hum introduced here is amplified hundreds of times by the audio amplifier following it. The amplification of the 120 cycle hum is especially pronounced when a good A.F. amplifier and loudspeaker are used. 226 type tubes are used chiefly for R.F. and A.F. amplification, having characteristics similar to the 201-A type tube for this work (see Fig. 54). They have a standard 4-prong UX base.

332. HEATER TYPE TUBES: Another type of A. C. tube which is superior in many ways to the UX-226 and which now is replacing the 226 type in all its uses, is the 227 type tube. In the 227 type of A. C. tube the electron emitting surface, or cathode, is a thin metal, oxide-covered thimble. The

alternating current flowing through the filament wire heats it to a red heat. The filament is electrically insulated from the cathode by an insulator, which being a good conductor of heat, conducts the heat from the filament to the cathode heating it to a red heat. The oxide covered cathodes emits the electrons which are then attracted to the plate and controlled by the grid. The external plate and grid circuits are returned to the cathode or electron emitter" and not to the filament.

This heating system has still greater thermal inertia than the filament in the 226 type, and as a result its temperature remains sufficiently constant to permit its being



METHODS OF RETURNING GRID
TO CENTER POINT

Fig. 255

used satisfactorily as a detector tube either of the grid bias or grid leak type or as a radio or audio frequency amplifier. The filament takes 1.75

should be of ample cross section to prevent excessive voltage drop. The A. C. filament leads should *always* be twisted together to guard against magnetic

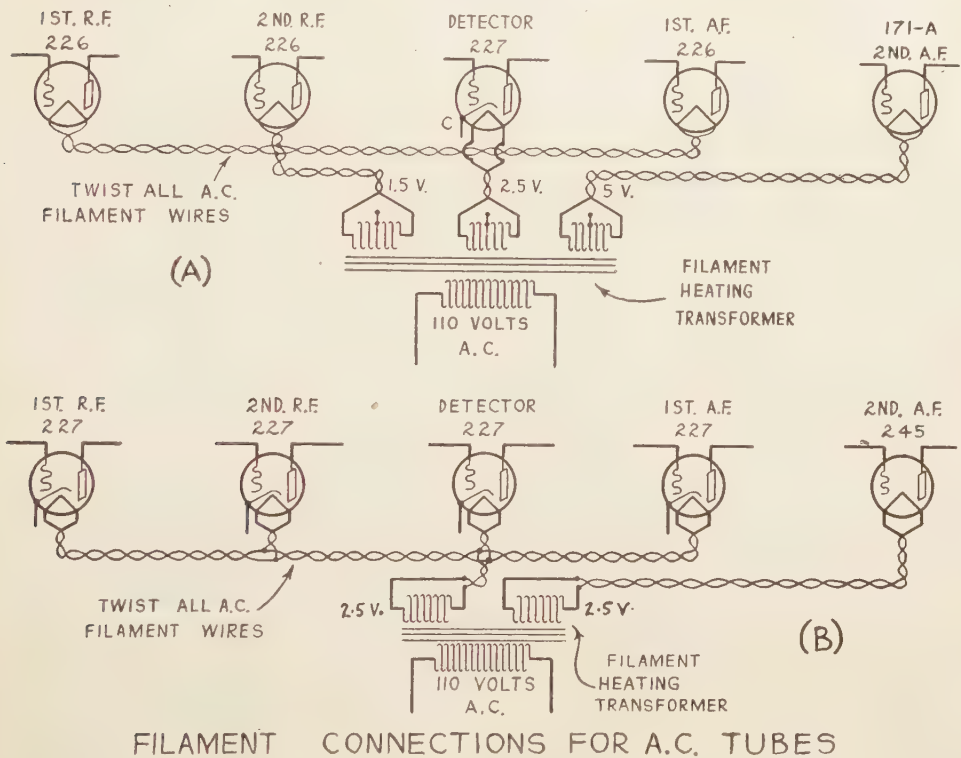


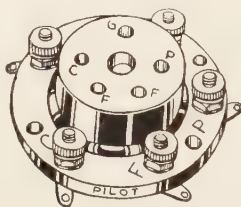
Fig. 256

coupling between these alternating current carrying wires and the sensitive amplifying circuits.

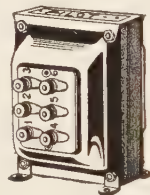
334. HUM CHARACTERISTICS OF A. C. TUBES: The relative amounts of hum produced because of unbalance in the filament circuits of 226 and 227 tubes is illustrated in Fig. 258. It will be noted that a 10 per cent displacement from the balance condition increases the hum voltage by about 60 millivolts in the 227 type and by about 550 millivolts for the 226 type. This is one of the reasons why the 227 tube is fast displacing the 226 type.

335. GRID BIAS AND VOLUME CONTROL: The 226 type tube should be operated with a grid bias such that a plate current of about three milliamperes flows (see Fig. 54). The "C" bias for 226 tubes is obtained by connecting a "C" bias resistor R in the center-tap line of either the center-tap resistor (Fig. 259 A), or the center tap on the transformer, as shown in Fig. 259 B. The "C" bias resistor is by-passed by a condenser C. This should be of at least .01 mfd. capacity for R. F. tubes and 1 mfd. for A. F. tubes. The path

of the plate current of the tube is shown by the arrows. This plate current flowing through the "C" bias resistor R on its way back to the B — terminal produces the fall of potential ($\text{Volts} = \text{Ohms} \times \text{Amperes}$) which is used for the "C" bias.



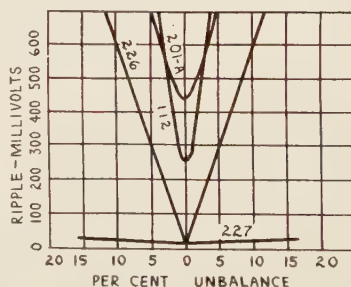
**Fig. 256A. 5-Prong
Socket for A.C.
Heater Type Tube**



**Fig. 257. Filament Heating
Transformer**

Grid bias for heater type (227 or 224) tubes can be obtained most simply by connecting a grid bias resistor R of proper value in the cathode lead as shown in Fig. 259 C and D. The plate current in these tubes flows from the plate to the cathode and thence to the B — terminal. As they must flow through the grid bias resistor, a fall of potential is produced, which is applied to bias the grid negatively. The grid return can be connected to the filament center point either by connecting it to the center tap of a 20 ohm resistor as shown in Fig. 259 C, or to the center tap of the 2.5 volt filament winding as shown in Fig. 259 D. This grounds the heater circuit.

The table of Fig. 260 gives the various resistance values of R to be used for proper grid bias for A.C. and power tubes. These should be used for best results. The grid bias voltages are given in Fig. 54. The resistance values given are for one tube. If two tubes are to be operated from the same grid bias resistor as in Fig. 259E, as double the plate current flows through the resistor only half the resistance value is required for the same voltage drop. Thus for two tubes divide these resistor values by 2, for three tubes divide the value by 3, etc.



HUM CHARACTERISTICS OF A.C. & D.C. TUBES.

Fig. 258

Volume control in A.C. tube electric sets cannot be accomplished in the ordinary ways due to unbalancing of the circuits, resulting in hum. One way is to connect a variable 0-20,000 ohm potentiometer across the primary of the antenna coil, with the variable contact at the ground side. This controls the amount of signal energy admitted to the R. F. amplifiers. Another way is by means of a high variable resistance R connected across the primary on one of the R. F. transformers. Stabilization can be secured by the use of any of the neutralized or bridge circuits, or oscillation control schemes explained in a previous chapter.

When heater type tubes are used, there is a slight lag in starting after the switch has been turned on. This is due to the fact that it takes several seconds for the heater filament to get enough heat to the cathode to start the emission of electrons. However, tubes with special insulator thimbles have been developed which heat up so rapidly that the tube is in full operation within a few seconds after turning on the switch.

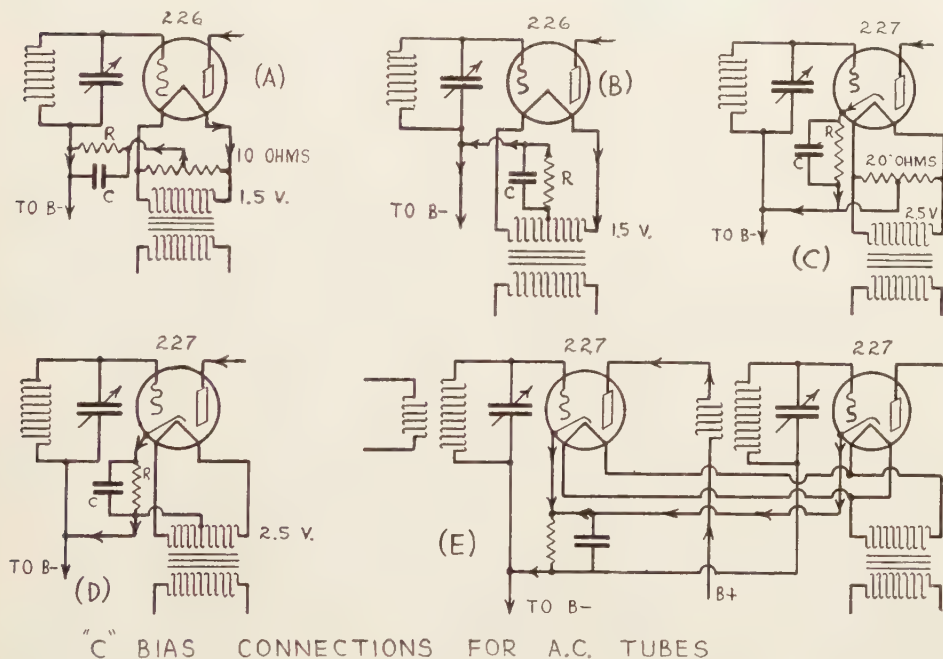


Fig. 259

336. **COMPLETE A. C. TUBE ELECTRIC RECEIVER:** Fig. 261 shows the circuit diagram for a complete six tube two dial control A. C. receiver using 226, 227 and 171-A tubes. A UX-280 full wave rectifier is used in the power unit. The power transformer supplies all the filament voltages for the tubes in the set as well as the filament and plate voltages for the rectifier tube. A jack is provided in the plate circuit of the 227 detector tube for plugging in a phonograph pick-up unit.

Fig. 262 shows the complete circuit diagram for an A. C. tube electric receiver using 227 type tubes for R. F., detector and A. F. stages and two 245 power tubes in push-pull in the output stage. The reader should examine these diagrams carefully as they contain much valuable and practical information relative to the connection and use of A. C. tubes and power tubes in modern high powered sets.

TUBE TYPES	GRID BIAS RESISTOR FOR A SINGLE TUBE (OHMS)											
	TUBE FILAMENT HEATED BY A.C.						TUBE FILAMENT HEATED BY D.C.					
	90 V. PLATE	135 V. PLATE	180 V. PLATE	250 V. PLATE	350 V. PLATE	425 V. PLATE	90 V. PLATE	135 V. PLATE	180 V. PLATE	250 V. PLATE	350 V. PLATE	425 V. PLATE
226	1700	1500	1800	—	—	—	—	—	—	—	—	—
227	2000	1800	2250	—	—	—	—	—	—	—	—	—
245	—	—	1350	1600	—	—	—	—	—	—	—	—
171-A	1900	1850	2150	—	—	—	1650	1700	2000	—	—	—
112-A	1300	1650	1600	—	—	—	850	1300	1350	—	—	—
210	—	—	—	1800	1950	1950	—	—	—	1500	1700	1750
250	—	—	—	1600	1400	1550	—	—	—	—	—	—
224	—	—	450	—	—	—	—	—	—	—	—	—

TABLE OF GRID BIAS RESISTORS

Fig. 260

337. **A. C. TYPE OF FOUR-ELECTRODE TUBE:** The perfection of the 224 type of four electrode A. C. screen-grid tube (see Fig. 54) has made the

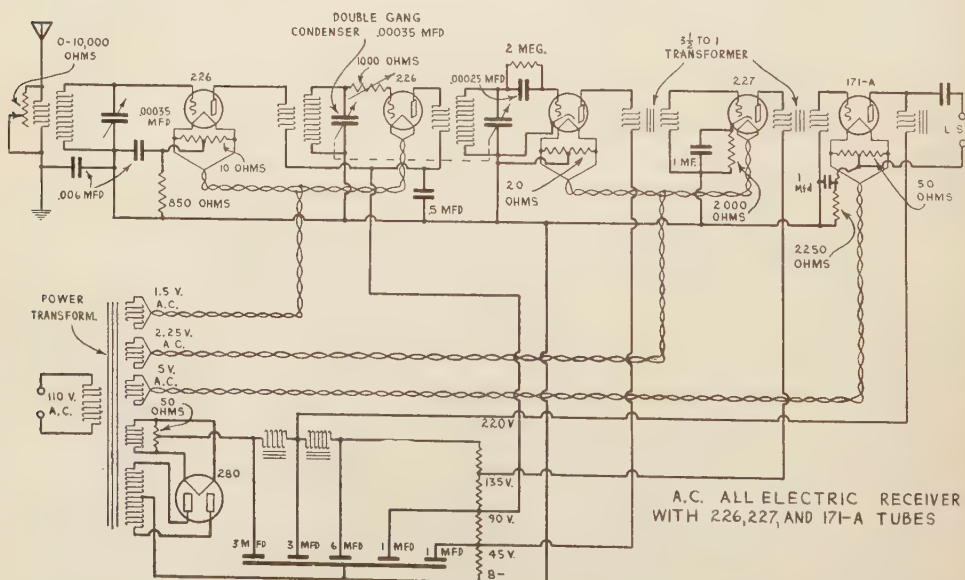
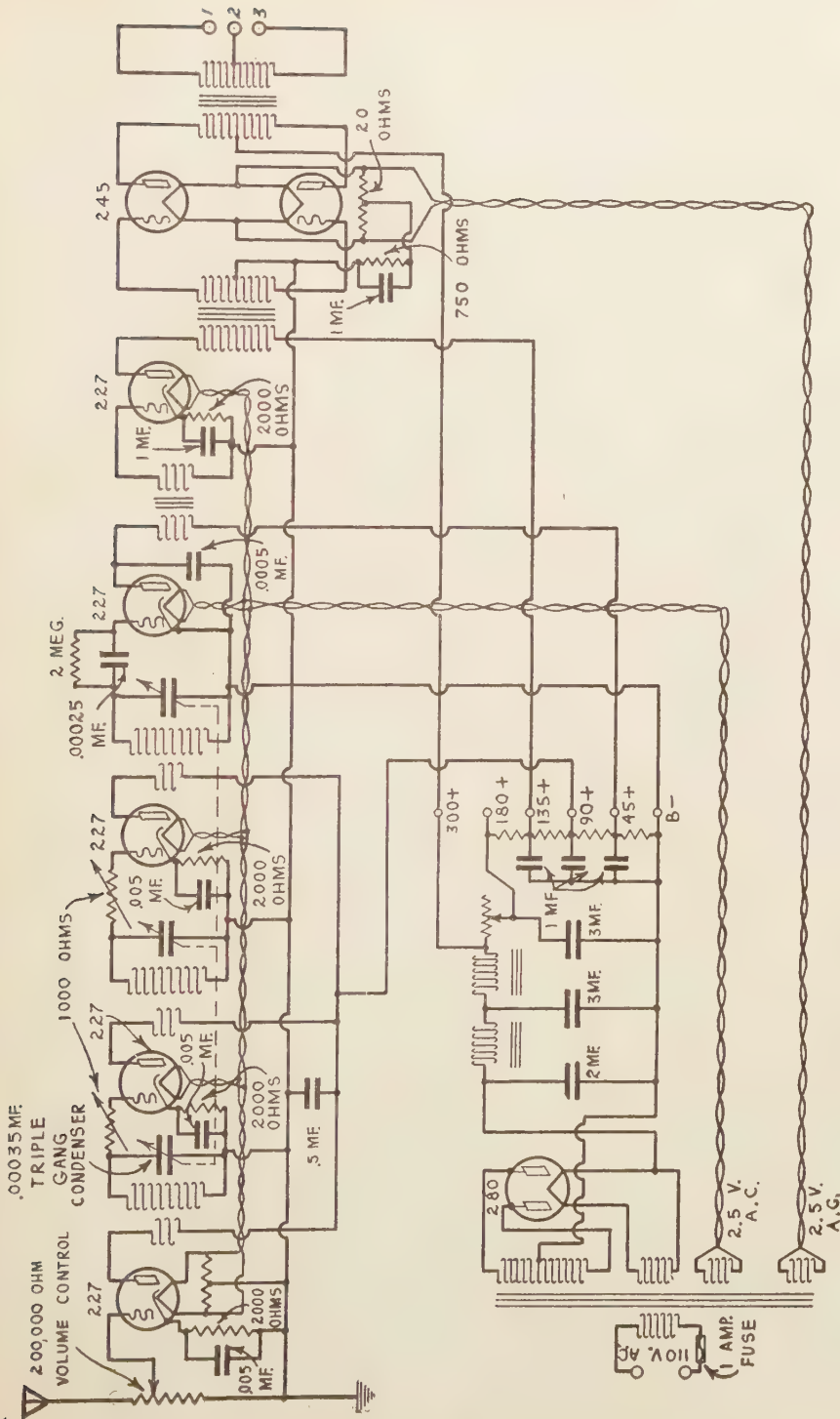


Fig. 261

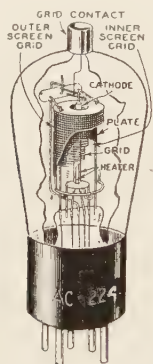


A.C. ELECTRIC RECEIVER WITH 227 AND 245 TUBES

Fig. 262

construction of A. C. tube screen-grid electric receivers a practical reality.

While the external appearance of this tube is similar to that of the 222 battery type screen-grid tube, the internal elements differ slightly. Starting at the center (Fig. 263) there is a tungsten heater, filament wire, and cathode similar to that in the 227 tube. The heater filament operates on raw A. C. at 2.5 and 1.75 amperes. Surrounding the filament and cathode is the control grid which is made of a fine spiral mesh. The plate is an open-ended cylinder placed outside of the control grid. The screen-grid is in three sections, the first is a fine wire mesh between the control grid and plate, the second a wire mesh surrounding the plate, while the third is a flat metal disc which connects the portions of the two mesh sections. The object of the screen-grid is to electrically shield the control grid from the plate. To accomplish this and obtain the neces-



MECHANICAL CONSTRUCTION OF THE ELEMENTS IN THE A.C. SCREEN GRID TUBE

Fig. 263

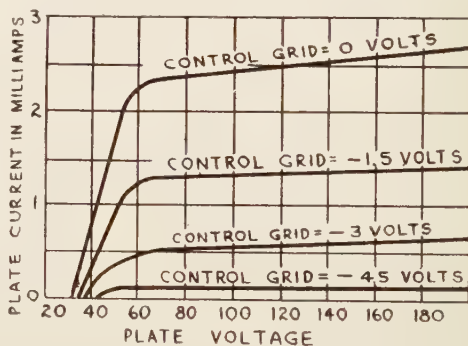


PLATE CURRENT, PLATE VOLTAGE CHARACTERISTICS OF 224 SCREEN GRID TUBE (SCREEN GRID VOLTS +45)

Fig. 264

sary degree of shielding requires the most accurate and careful mechanical construction of the electrodes located in the small space within the tube. The connection for the control grid is brought out through the glass tube to a cylindrical metal cap on top. The base is of standard UY type having five prongs. The position of the cathode, plate, and filament prongs is similar to those on the 227 tube. The screen-grid prong corresponds to the grid prong on the 227 tube.

The plate and grid characteristics of this tube (see Fig. 54) are slightly better than those of the 222 battery type screen-grid tube. The theoretical amplification factor of 420 is much higher and the plate impedance of 400,000 ohms is much lower. The grid to plate capacity is only 0.01 mmfd.

The high plate impedance of this tube raises the same problems regarding coupling methods that were discussed regarding the 222 tube in Chapter 17. Of course, it is highly important that a type of plate circuit be selected which will have the required external high impedance. As these same conditions prevail in the application of the 224 tube they will not be discussed again here.

The exceptional sensitivity resulting from the high amplification factor which can be obtained in practice makes possible the construction of complete A. C. tube electric receivers having great sensitivity and operating from small copper screen antennas located within the receiver cabinets. Of course the amplification factor which can be obtained in practice is only a small fraction of the theoretical value. The low grid to plate capacity makes it possible to build multi-stage high gain R. F. amplifiers without troublesome oscillation provided proper precautions are taken to prevent feedback outside of the tubes themselves. The 224 tube can be used as an R. F. amplifier, or as a detector by grid leak or grid bias method, and as an A. F. amplifier with proper coupling.

338. HUM CHARACTERISTICS OF 224 TUBE: The characteristic curve of Fig. 264 shows the variation of plate current with plate voltage change for various control grid voltages, and screen-grid voltage kept constant at plus 45 volts. It can be seen that for any particular fixed control grid voltage, the plate current changes very little as the plate voltage is varied between the limits of 90 and 180 on the plate. Thus for a control grid voltage of -1.5 volts the plate current changes less than 0.2 milliamperes as the plate voltage is varied from 90 to 180 volts. In a 201-A three electrode tube this change would be about ten milliamperes. The practical value of small plate current variations can be readily seen when modern radio power supply systems for electric A. C. operated receivers are considered. These power supply systems are subject to changes in voltage which affect the plate voltage. The screen-grid tube remains unaffected by such small voltage changes, and is unlikely to reflect, to any great degree, fairly large variations in plate supply.

339. A. C. SCREEN-GRID ELECTRIC RECEIVER: Fig. 265 shows the complete circuit diagram for an A. C. operated screen-grid receiver using 224 screen-grid tubes and 245 output tubes in push-pull. The volume is controlled by means of the potentiometer in the screen-grid circuits of the R. F. tubes. Moving the slider varies the potentials of the screen-grids and therefore controls the amplification of these tubes. This is perhaps the best type of volume control to use on sets of this type. The power transformer supplies the filament voltages for all the tubes as well as the filament and plate voltages for the 280 type rectifier tube.

A 224 screen-grid tube is used as a bias power detector. The grid bias is adjusted to the value for best operation by means of the variable 0-30,000 ohm resistor in the cathode circuit. When this has once been set it need not be disturbed.

The first audio stage is resistance coupled to the detector tube in order to put a high impedance load in the plate circuit of this tube for high amplification and good frequency response. The use of an ordinary audio transformer in this position would not be satisfactory due to poor impedance match with the plate circuit of the detector tube. The second audio stage is a push-pull stage using 245 power tubes. The individual radio frequency stages or else the individual coils and possibly the tubes of a high gain receiver of this type must be well shielded and the location of parts and wiring carefully considered to prevent coupling between the stages with consequent uncontrollable oscillation.

The grid bias resistor, screen-grid circuit and plate circuit of each R. F. stage

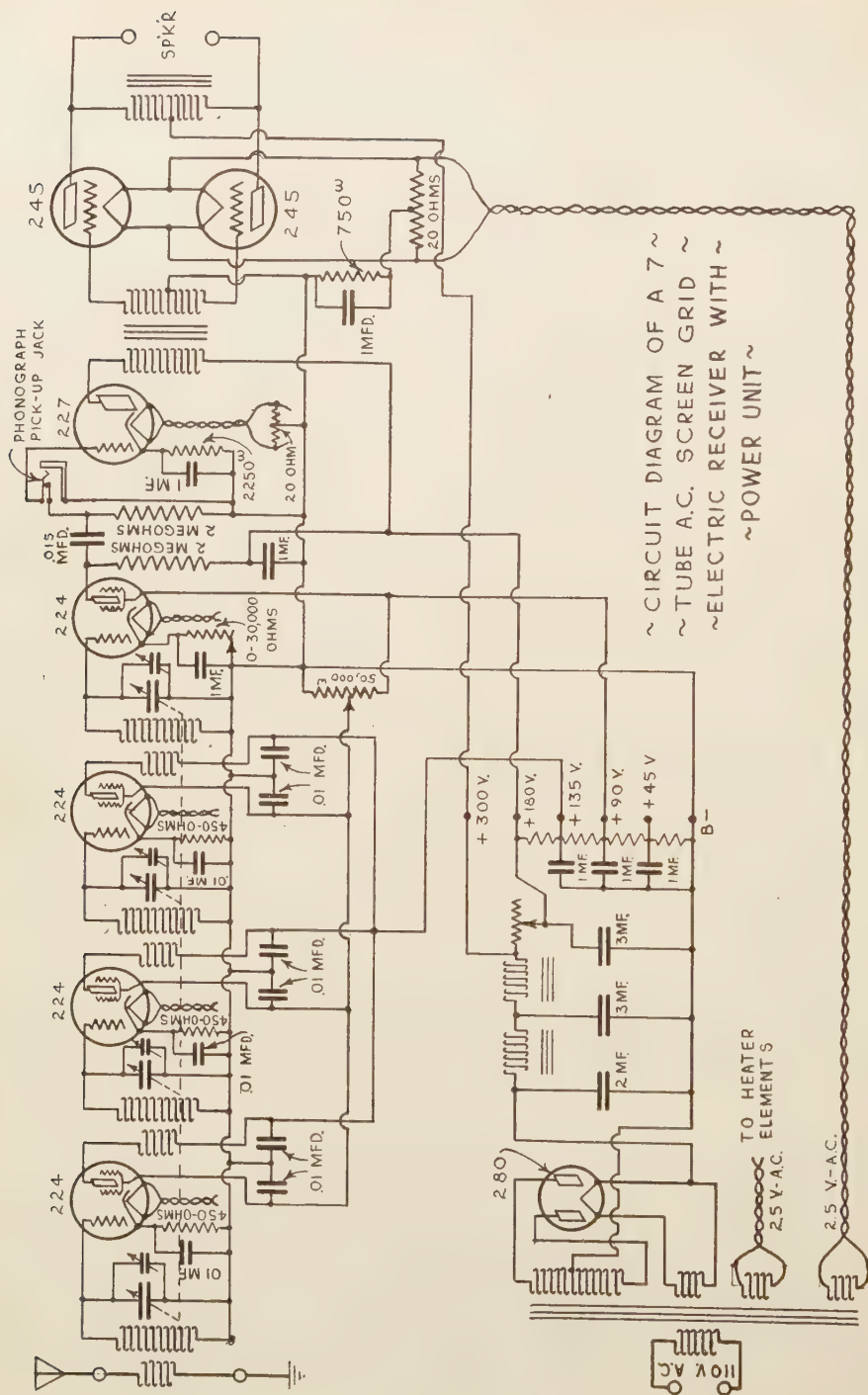
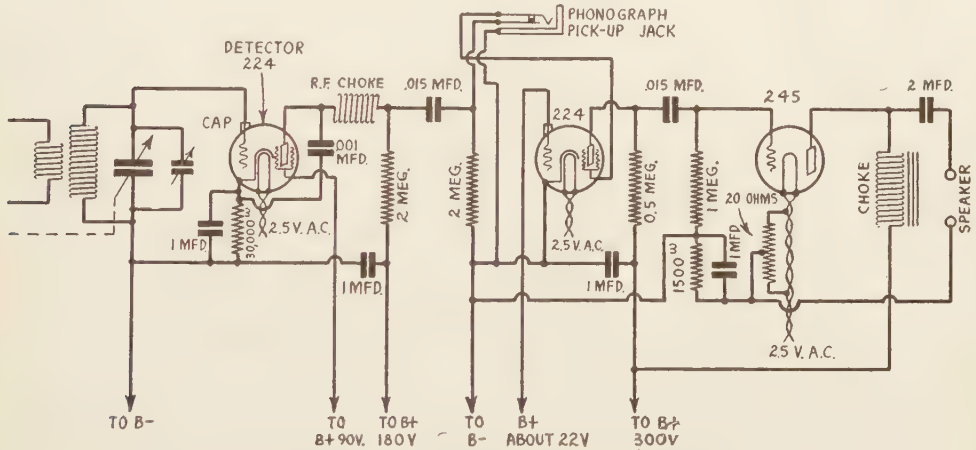


Fig. 265

must be properly by-passed by a low impedance by-pass condenser path to prevent coupling in the "B" supply unit.

Fig. 265A shows the audio portion of the receiver of Fig. 265 arranged for using a screen-grid tube connected as a space charge grid tube in the first audio stage. Only a single 245 tube is used in the output. In a set of this kind it is important that the coupling resistors used be of the heavy duty type capable of safely carrying the current without changing their resistance or becoming "noisy" in service. Notice that the usual grid connections in the space-charge



SPACE CHARGE GRID AUDIO FOR RECEIVER OF FIG. 265

Fig. 265A

grid tube are reversed, the signal is impressed on the outer screen-grid and a fixed positive voltage is impressed on the inner grid. This gives a very high gain (about sixty) so that only two audio stages are necessary even though resistance coupling is used.

340. HUM IN ELECTRIC RECEIVERS: An electric receiver should work without hum or other extraneous noise. Absolutely silent operation is difficult to obtain, although in many well designed receivers the hum is reduced to a value where it does not cause any objectionable disturbance and is practically unnoticeable excepting in the short interval between programs and announcements of stations.

One frequent cause of A. C. hum in home built and even some factory built receivers, is the interaction between the magnetic fields of the parts in the power pack and the audio amplifier.

As shown in Fig. 266 the power transformer used in the power unit, as well as the filter chokes, and the audio transformers used in the set have electro-magnetic fields which spread to a considerable distance in their vicinity. If these instruments are placed close to each other so that the fields interact, an alter-

nating voltage will be set up in the chokes and the audio frequency amplifier transformer coils and will be amplified along with the signals, producing a bad hum in the loudspeaker. A slight A. C. voltage induced in the first audio transformer is especially liable to cause troublesome hum as this voltage is amplified several hundred times by the audio amplifier. The use of a resistance coupled first audio stage as in the circuit of Fig. 265 eliminates this, since a resistance coupling unit does not have coils to pick up induction effects. The use of a resistance coupled audio stage following the detector in A. C. tube electric receivers has become very popular for these reasons.

The power transformer, the chokes, and the audio transformers (especially the first stage one) must be kept a suitable distance apart to avoid this trouble. Thus distance is best determined by experiment with the particular units used, by shifting the parts around. This trouble can also be reduced effectively by locating the parts in such relation to each other that the magnetic fields are at right angles to each other. This is similar to the idea involved in Fig. 109 of Chapter 12.

Also keep all grid and plate leads as short as possible, and away from all circuits carrying alternating current. The wires carrying A. C. should be twisted to prevent magnetic induction effects.

Faulty A. C. tubes or faulty rectifier tubes are also a frequent cause of hum in a set. They can be detected by plugging new tubes in their places while the receiver is operating.

Noisy sets usually present quite a problem, as it is usually difficult to locate the source of the trouble. To locate the cause of noises, first find out if the scratchy noises are coming from the aerial circuit or from the set, tubes or batteries. To do this, first operate the set so the scratchy noises come in loudly. Now disconnect both the aerial and ground from the set. If the noises stop, it indicates that they have been caused by some outside electrical disturbance sending the electrical impulses to the aerial. In this case, you will have to try to locate the cause of the trouble and eliminate it.

If the noises continue when you disconnect the aerial, it indicates that they originate in your equipment. Check over every connection to make sure it is made tightly. Now try a new tube in each socket at a time to find out if one of your regular tubes are causing the noises.

Hum or howling is sometimes caused by one or more microphonic tubes in the set. To locate a microphonic tube, operate the set so that the hum or howl comes in very loud. Now press your hand firmly down on each one of the tubes in the set in turn. When you do this to the microphonic tube, the

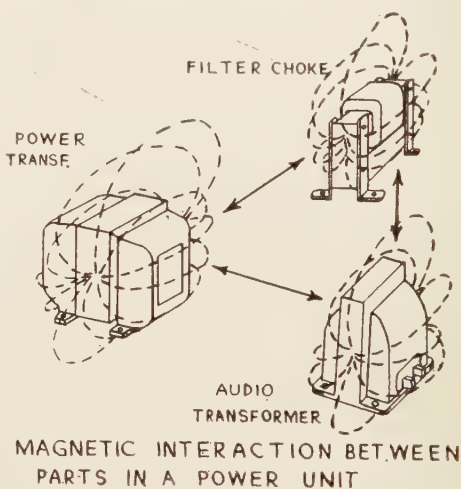


Fig. 266

hum will decrease in strength or disappear altogether. You should either replace it with a new tube or put one of the weighted "howl-arresters" made for this purpose on it. They can be purchased at radio stores for about fifty cents each. Placing your speaker too close to the set sometimes causes a hum or howl due to the strong sound waves from the speaker, setting up a mechanical vibration of the tubes. When the elements vibrate (at the audio frequency), the distance between them changes, resulting in plate current changes which are amplified by the audio amplifier, resulting in a hum or a bad howl. The remedy for this is to mount the speaker at some distance from the set or use howl-arresters on the sensitive tubes located by the above tests.

REVIEW QUESTIONS

1. State several advantages of electric operation of a receiver over battery operation.
2. Define: (a) Battery-operated set.
(b) Socket-powered set.
(c) Electric set.
(d) A. C. tube electric set.
(e) D. C. tube electric set.
3. Describe the series-filament method of electric set operation. What are its practical limitations?
4. Why is it not practical to heat the filaments of ordinary 201-A tubes with alternating current in a receiver?
6. Why is it possible to use raw A. C. on the filament of the last audio tube without objectionable hum?
7. What special construction features does the 226 tube contain to reduce hum tendencies? What features do the separate heater type tubes contain?
8. Describe a practical D. C. electric set.
9. State several advantages of separate heater type tubes over 226 type tubes for A. C. filament operation.
10. What supplies the low A. C. filament voltages required for A. C. tubes?
11. Draw a practical circuit for obtaining proper "C" bias for two 226 tubes used as R. F. amplifiers. Draw a practical circuit for obtaining proper "C" bias for two 227 tubes used as R. F. amplifiers. Explain how the "C" bias voltage is obtained in both cases.
12. Describe the construction of the A. C. type of four-electrode tube (224 type).
13. State several causes of hum in A. C. tube electric receivers, and their remedies.
14. Explain two advantages of using a resistance coupled audio stage following the detector in an A. C. tube electric receiver.

CHAPTER 20

SHORT-WAVE RECEPTION

SHORT-WAVE BROADCASTING—AMATEUR TRANSMISSION—WHAT SHORT WAVES ARE—PECULIARITIES OF SHORT-WAVE RECEPTION—PLUG-IN COILS—SHORT-WAVE TUNER DESIGN—REGENERATION—SHORT-WAVE RECEIVER—SHORT-WAVE BANDS—SHORT-WAVE RESULTS—TIME CHART—SCREEN-GRID S. W. RECEIVER—SHORT-WAVE RECEIVER OPERATION—ELECTRIC OPERATION OF S. W. RECEIVERS

341. **SHORT-WAVE BROADCASTING:** Contrary to popular opinion, short-wave transmission and reception, which is becoming so widespread, is not a new discovery. Amateurs have been using the short-wave lengths for some time. Reports of reception, on one or three tube receivers, of short-wave stations thousands of miles away has so fired the imagination of many people that short wave reception has become very popular. Many of the leading broadcasting stations are transmitting their programs on short waves simultaneously with their regular higher wave broadcasts (200 to 580 meters). These short-wave transmissions have been heard almost all over the world, far beyond the distance obtainable on their regular broadcast waves.

342. **AMATEUR TRANSMISSION:** Owners of the thousands of privately owned amateur stations throughout the world have done much to increase our store of knowledge concerning short-wave transmission and reception. Owners of moderately equipped stations in widely scattered parts of the world have become neighbors and exchange almost daily conversations with their friends. The extremely low power used in most cases makes these achievements seem almost incredible to those familiar only with the large broadcasting stations operating on the regular broadcast wave-lengths, with as much as 50,000 watts of power in some cases.

343. **WHAT SHORT WAVES ARE:** Popular usage of the term "short-wave" has come to denote the waves below 200 meters in wavelength. Remembering from a previous chapter that the relation between wavelength and frequency for radio waves is,

$$\text{Wavelength} = \frac{300,000,000}{\text{Frequency in cycles per second}}$$

it can be seen that the lower the wavelength, the higher the frequency. Thus, a wavelength of 200 meters corresponds to 1,500 kilocycles. A wavelength of 10 meters corresponds to 30,000 kilocycles. A chart giving the wavelengths corresponding to the various frequencies and vice-versa is given in Appendix D.

Speaking in terms of frequency then it may be said that a short-wave transmitting station is any station transmitting on a frequency of about 1,500 kc. or higher.

344. PECULIARITIES OF SHORT-WAVE RECEPTION: Some of the peculiar effects encountered in short-wave reception have already been explained in Chapter 3. These include fading and skipping. In designing receivers for short-wave (high frequency) reception, many problems are encountered which are not met with in dealing with the higher wavelengths (lower frequency). Due to the high frequency of the currents received, the layout of all parts and wiring in the set must be given much thought, as inductance and capacity effects between wires and between coils, etc., are very marked. All wires from grids and plates of tubes should be kept short and well separated. Unless care is exercised in wiring the variable condensers, troublesome hand capacity effects are liable to result. This makes tuning very difficult, and is manifested by a change in the tuning of the set whenever the hand is brought near the tuning dial. The wire from the grid of the tube to the tuning coil and condenser should always be connected to the stator plates of the tuning condenser, and the rotor plates should go to the grid return circuit. Complex circuits using multi-stage amplifiers are usually either unstable or have too many operating controls to be of value. Modern short-wave sets usually consist of a stage of R. F. amplification followed by a regenerative detector, either with or without one or two stages of ordinary transformer coupled audio frequency amplification. The use of a stage of tuned screen-grid R. F. amplification increases the sensitivity greatly.

345. PLUG-IN COILS: Receivers designed for the ordinary broadcast waveband (200 to 600 meters) are required to cover a radio frequency range from 1500 to 500 kilocycles (see chart in Appendix D). This is a range 1000 kilocycles wide. This tuning range of 1000 kc. is usually covered easily by using one coil and a variable tuning condenser, usually of 0.00035 mfd. capacity for each R. F. stage. If the dial on the set has 100 divisions, and straight line frequency condensers are employed, each division on the dial covers 10 kc. or 10,000 cycles. We learned in a previous chapter that this represents one broadcast channel. It requires a 10 kc. band to properly transmit music and speech. This is independent of the frequency of the carrier wave. No matter whether the program transmission is being accomplished at 600 meters or on 10 meters, the same width channel (10 kc.) is required for good results. Therefore at standard broadcast wavelengths (200 to 600 meters) one division on the tuning dial accommodates about 10 kc. or one broadcast channel.

The short-wave band from five meters to 200 meters (60,000 to 1,500 kc.) is 58,500 kilocycles wide. This is nearly 60 times as wide as the broadcast range, and it means that if a short-wave receiver were designed to cover the entire short-wave band with one tuning coil and condenser, this coil and condenser would have to cover a tuning range of 58,500 kc. Such a tuning system is impossible to design, with any degree of efficiency. Also, if the tuning dial had 100 divisions, a movement of the dial by one division would change the tuning frequency by 585 kc. Thus over 58 short-wave broadcasting channels would be passed over by a movement of one division of the dial. The tuning would be hopelessly sharp.

The alternative is either to design the tuner to cover a particular limited waveband the listener wants to receive, or to design it with either removable

coils or condensers, or both. In the latter case the coils or condensers can be changed for each of the many narrow wavebands into which popular short-wave transmission is now divided. These are, the 160 meter, 80 meter, 40 meter and 20 meter amateur bands and the broadcast short-wave bands at 50, 25 and 20 meters. Most short-wave sets are now built with a non-removable variable tuning condenser and number of removable plug-in coils which are wound for tuning to the various wavebands. Fig. 267 shows a set of plug-in coils used in a popular short-wave receiver. These must be wound very accurately, especially for the shorter waves, as one turn of wire makes a great

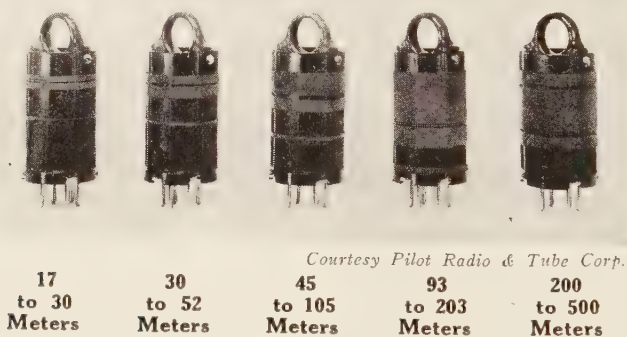


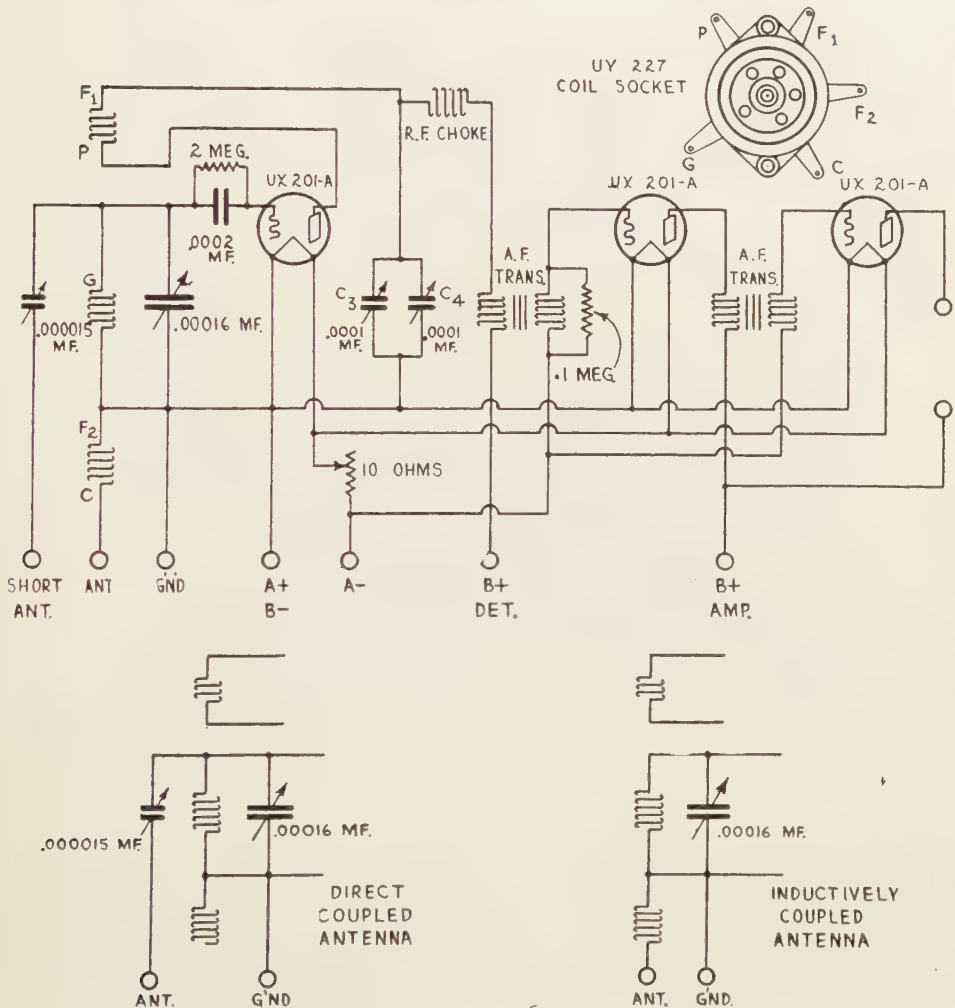
Fig. 267. Plug-In Coils For Short Wave Receiver

difference in the tuning range. Some receivers are being built with removable plug-in variable condensers of various sizes.

346. **SHORT-WAVE TUNER DESIGN:** When the one-tuning-condenser plug-in coil arrangement is used, it is necessary to use a rather smaller condenser than is common in broadcast work in order to get down to the low wavelengths around 17 meters. Ordinary 0.00035 mfd. condensers have a minimum capacity which is too high to enable the set to get down to 17 meters if a practical coil with any turns at all is to be used with it. Tuning condensers having a smaller maximum capacity employ less plates and therefore their minimum capacity (plates all un-meshed) is very much lower. Consequently they are always used in short-wave receivers. A common short-wave set tuning condenser size is about 0.00016 mfd. maximum capacity. This usually has a total of about 8 or 10 plates.

347. **REGENERATION:** Regeneration can be obtained by any of the various means discussed in Chapter 9, but in short-wave work the condenser feedback method seems to be most popular on account of its many advantages. Feedback by means of the common rotating tickler usually results in rather critical regeneration control, that is, the receiver goes in and out of oscillation suddenly. Regeneration control with a fixed tickler shunted by a high variable resistance suffers from scratchy noises introduced by most variable resistances when they are being adjusted, and the hand capacity effects on the short waves. It is important to note that all variable condensers employed in short-wave

receivers should have good electrical contact between rotor and frame to prevent scratchy noises in the receiver. Many of the high grade condensers employ short flexible pigtail connectors from rotor to frame to insure good elec-



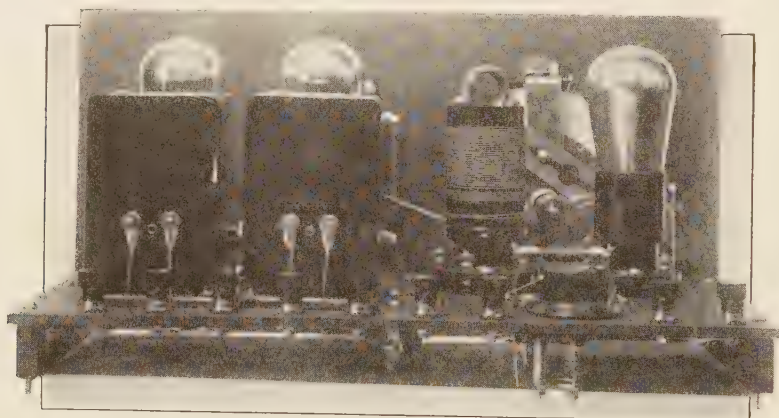
CIRCUIT DIAGRAM OF THE WASP SHORT-WAVE RECEIVER

Fig. 268

trical connection. Regeneration in broadcast receivers fell into disrepute because it made them too selective. In practice it was usually pushed to the point where it cut the side bands and ruined the tone quality. In short-wave receivers, regeneration is almost always used. Here it serves two purposes: it makes the

receiver more sensitive and makes it easier to find the stations, since by setting the receiver into oscillation, the various short-wave transmitters can be located by the whistle produced when they are passed over. This is a great advantage where several stations may come in and out on one degree of tuning on the dial. Then the regeneration is backed down to stop the whistle and the program is there.

348. **SHORT-WAVE RECEIVER:** Fig. 268 shows the circuit diagram of a popular three-tube regenerative receiver designed to cover both the short-wave and broadcast wavebands. Five plug-in tuning coils are used with a 0.00016 mfd. tuning condenser. The wavebands covered with the various coils are as follows: 17 to 30 meters, 30 to 52 meters, 45 to 105 meters, 93 to 203 meters and 200 to 500 meters. The coils are shown in Fig. 267 and are wound with silk covered wire carefully arranged. This receiver is for battery operation. When an ordinary broadcast antenna is used, it is connected to the "short ant." binding post. This connects the antenna directly to the grid of the detector through the 0.000015 mfd. midget condenser, which reduces the



Courtesy Pilot Radio & Tube Corp.

Fig. 269. Wasp 3 Tube Short Wave Receiver

natural frequency of the antenna circuit. When a short antenna about 20 feet long is used, it should be inductively coupled to the receiver by connecting it to the "ant." binding post. The two 0.0001 mfd. midget variable condensers are used for regeneration control. When short-wave stations are being received, one of these is set at minimum capacity and regeneration is controlled with the remaining one. When the broadcast coil is used, one of these condensers is set at maximum capacity and regeneration is controlled with the remaining one.

The grid leak size is important in short-wave sets. It is sometimes found that higher values of grid leak greatly controls the ease with which the detector goes into oscillation. The 0.1 megohm fixed resistor connected across the secondary of the first audio transformer is used to reduce the harsh rasping noise which occurs just as the detector tube of a short wave receiver goes into oscillation. A good idea of the correct layout of parts for a short-wave receiver

can be obtained from the photograph of Fig. 269. This is the receiver shown in the circuit diagram of Fig. 268. All grid and plate leads are kept well separated, and do not run parallel to each other for any appreciable distance.

349. **SHORT-WAVE BANDS:** A list of the short-wave wavebands, arranged for 1929, is given below. The short-wave receiver can be designed to receive those wavebands in which the listener is interested.

KILOCYCLES	WAVELENGTH IN METERS	CLASS OF STATIONS
1500—1715	200—175	Mobile
1715—2000	175—150	Amateur Fone and C. W.
2000—2250	150—133	Mobile and Fixt
2250—2750	133—109	Mobile
2750—2850	109—105	Fixt
2850—3500	105—85	Mobile and Fixt
3500—4000	85—75	Amateur C. W.
4000—5500	75—54	Mobile and Fixt
5500—5700	54—52	Mobile
5700—6000	52—50	Fixt
6000—6150	50—48.8	Broadcasting
6150—6675	48.8—45	Mobile
6675—7000	45—42.8	Fixt
7000—7300	42.8—41	Amateur C. W.
7300—8200	41—36.6	Fixt
8200—8550	36.6—35.1	Mobile
8550—8900	35.1—33.7	Mobile and Fixt
8900—9500	33.7—31.6	Fixt
9500—9600	31.6—31.2	Broadcasting
9600—11,000	31.2—27.3	Fixt
11,000—11,400	27.3—26.3	Mobile
11,400—11,700	26.3—25.6	Fixt
11,700—11,900	25.6—25.2	Broadcasting
11,900—12,300	25.2—24.4	Fixt
12,300—12,852	24.4—23.4	Mobile
12,852—13,350	23.4—22.4	Mobile and Fixt
13,350—14,000	22.4—21.3	Fixt
14,000—14,400	21.4—20.8	Amateur C. W.
14,400—15,100	20.8—19.85	Fixt
15,100—15,350	19.85—19.55	Broadcasting
15,350—16,400	19.55—18.3	Fixt
16,400—17,100	18.3—17.5	Mobile
17,100—17,750	17.5—16.9	Mobile and Fixt
17,750—17,800	16.9—16.85	Broadcasting
17,800—21,450	16.85—14	Fixt
21,450—21,550	14—13.9	Broadcasting
21,550—22,300	13.9—13.45	Mobile
22,300—23,000	13.45—13.1	Mobile and Fixt
23,000—28,000	13.1—10.7	Unassigned
28,000—30,000	10.7—10	Amateurs and Experiments
30,000—56,000	10—5.35	Unassigned
56,000—60,000	5.35—5	Amateurs and Experiments
60,000 and up	5 and down	Unassigned

Up to date lists giving the wave lengths and frequencies of the various short-wave transmitting stations can be obtained by reference to current radio magazines or newspapers.

The International Amateur "10 meter band" reaches from 10 to 10.7 meters and many additional stations can be heard there, especially by daylight at long distance only. The International Amateur "20 meter band" reaches from 20.9

to 21.4 meters. It is a long distance wave and is at its best when one or both stations are in daylight, i.e., both the transmitter and the receiver. Twenty meter stations are frequently very weak nearby and loud at a distance of 1,000 miles or more, on account of the "skipping" effect.

The 40 meter band (41 to 42.8 meters) is the busiest of all bands because it is both a good semi-local and "extreme D-X" wave. In addition it has some of the properties of the 20 meter wave and will work well into daylight before failing.

350. SHORT-WAVE RESULTS: When receiving on short waves it must be remembered that some practice in tuning is necessary with any particular receiver before any long distance reception can be expected. Also the range of most short-wave transmitters varies with the time, weather, location, interference, operator's skill, and adjustment. It is entirely possible for the same small set to communicate with stations 1000 miles or further away one night, and fail entirely to get "out of the town" the next night. Also, when looking up transmitting station time schedules the differences in time existing at various parts of the world must be taken into account. A discussion of the many vagaries of short-wave transmission such as fading, skipping, etc., was given in Chapter 3.

351. TIME CHART: The time chart below gives the time differences existing at various parts of the world. This chart is given with New York City at 6 P. M. Eastern Standard Time.

City	Time Chart	
	Eastern Standard Time	Numbers of hours ahead of New York City
New York City	6:00 P. M.	
Chicago	5:00 P. M.	
Denver	4:00 P. M.	— 1 hour (behind)
San Francisco	3:00 P. M.	— 2 hours (behind)
London	11:00 P. M.	— 3 hours (behind)
Paris	11:00 P. M.	+ 5 hours
Madrid	11:00 P. M.	+ 5 hours
Rome	Midnight following day	+ 5 hours
Petrograd	1:00 A. M.	+ 6 hours
Buenos Aires	7:00 P. M.	+ 7 hours
Bombay, India	4:00 A. M.	+ 1 hour
Calcutta, India	5:00 A. M.	+ 10 hours
Melbourne, Australia	8:30 A. M.	+ 11 hours
Sydney, Australia	9:00 A. M.	+ 14.5 hours
		+ 15 hours

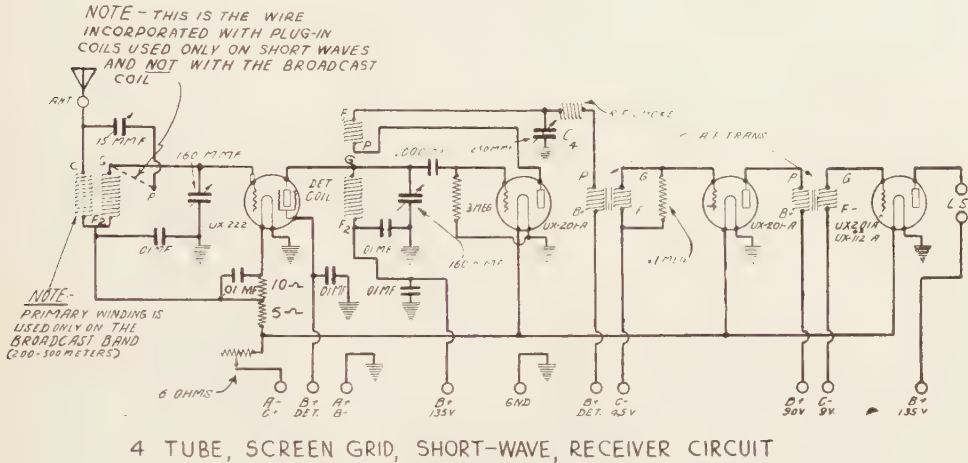
Thus when it is 7:00 P. M. Eastern Standard Time in New York City, it is midnight in London. (This would be 8:00 P. M. Eastern Daylight Saving Time.)

352. SCREEN-GRID S. W. RECEIVER: Fig. 270 shows the circuit diagram of a battery operated combination short-wave and broadcast wave receiver designed by Robert S. Kruse, one of the leading authorities on short-wave apparatus design.

The set consists of the usual condenser controlled regenerative detector and two stage audio amplifier, preceded by a stage of tuned screen-grid R. F. amplification using a UX-222 tube. The R. F. and detector stages are enclosed in aluminum shielding cans and both the front and sub-panel are made

of aluminum. This receiver represents the design practice employed in the finest battery operated short-wave units available at the present time. A rear view of the complete receiver is shown in the photograph of Fig. 270 A.

Two sets of five plug-in coils (one for the R. F. stage and one for the de-



resulted in throwing light on the causes of the difficulties, and in developing practical remedies for their removal. In the first place, short-wave receivers are almost always of the regenerative type in order to secure the tremendous amount of amplification inherent in the regenerative detector, and to make them suitable for continuous wave (CW) reception. They are therefore extremely sensitive (especially when they also contain a tuned R. F. stage of amplification), and must be capable of maintaining the most critical adjustments when the detector is operated just below the oscillation point. Also, most short-wave receivers are used with earphones when weak distant stations are being received. This requires that in an A.C. operated short-wave receiver the hum must be at an absolute minimum to permit of the use of earphones. An amount of A.C. hum which may be entirely unnoticed in the average broadcast receiver using a loud speaker may make a set worthless for earphone reception.

Furthermore, a stable plate voltage supply (especially on the regenerative detector) is vital to success in short-wave reception. The regeneration control is usually in a state of critical adjustment, consequently if the "B" power unit does not maintain stable output voltages it will cause the tube to spill over, necessitating constant readjustment and resulting in unsatisfactory operation.

A detailed study of the use of A.C. tubes in short-wave receivers reveals the fact that if A.C. tubes are merely substituted for the battery type tubes used in the usual short-wave receiver circuits, strong hums appear in the output, and regeneration control is very erratic.

The hums fall into two classes, the first is the "residual hum" because it can be heard in the headphones at all positions of the tuning dials. It originates in the audio circuit. The second class is the "tunable hum" as it can be brought in on several places on the coils, and can be brought in or out by operating the tuning dials. It appears to have definite wavelengths.

The residual hum is due mainly to 60 cycle induction caused by the construction of the usual heater type A.C. tubes (227 type) used as a detector. It is also present in the two audio tubes.

The hum is caused by an unbalanced field created by the filament. The standard 227 tube has a straight filament run through the center of the heated cathode, as shown at the left of Fig. 271 A. It is apparent that at one instant the bottom of the filament will be positive while the top is negative, shortly followed by a reversal of the heating current which makes the bottom of the filament negative with the top positive. The electronic field within the cathode is thus rapidly twisted back and forth during each alternation of the heating current. A noticeable hum results due to the induction effects.

Special 227 tubes have been designed to avoid this. In these tubes the heating filament is doubled back on itself within the cathode cylinder after the fashion of a hairpin. In this arrangement, the electronic field is neutralized at every point and no upheavals take place on the reversals of the heating current. This is shown at the right of Fig. 271 A. However, some 227 tubes which employ the double filament mounting are not satisfactory because of an insulating sleeve that is incorporated to hold the filament in place, and also because of the comparatively large amount of residual gas remaining in the tube

Too much audio gain is undesirable for other reasons than A.C. hum amplification. Microphonic detector noises are always an annoyance resulting from excessive audio amplification. An audio system particularly suited for use with A.C. electric operated short-wave receivers is shown in the complete receiver diagram of Fig. 271C. It consists of a detector working directly into a high resistance—high capacity coupling unit, onto the grid of the first audio tube. This audio stage is then coupled to the last audio tube through a standard transformer with the primary phase arranged for negative howl tendency.

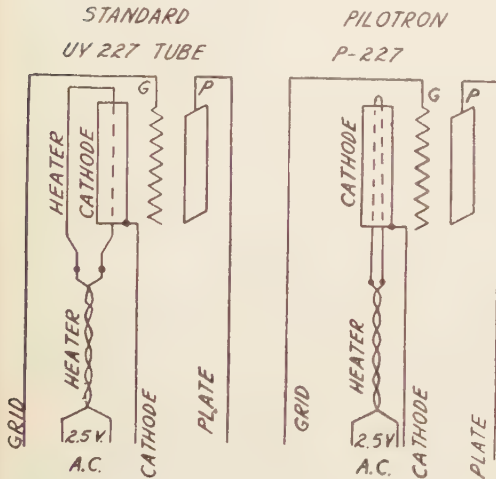


Fig. 271A—Filament Construction of A. C. Heater Tube Used in Short Wave Work.

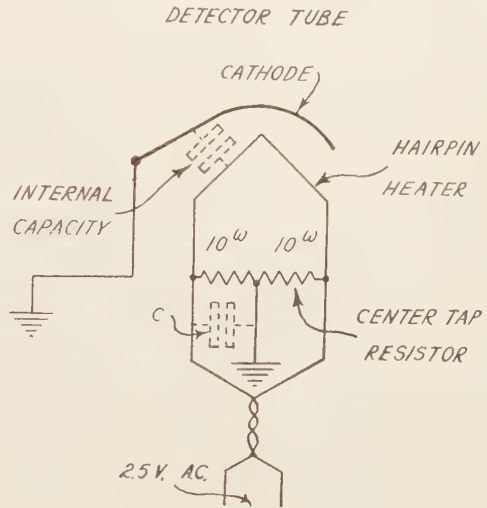


Fig. 271B—Oscillatory Filament Circuit in Detector Tube.

The use of this first resistance stage reduces the residual hum much more than the reduction in audio amplification explains. A net gain in hum reduction results from the use of the resistance coupling in the first stage. The resistance units do not act like A.C. pick-up coils, as would the audio transformer windings in this location.

The tunable hums arise from high frequency oscillations occurring in the set, and modulated by the 60 cycle current. Some combination of inductance and capacity in the set acts as a transmitting circuit. One of these circuits occurs in the filament circuit of the detector tube as shown in Fig. 271B.

The capacity of the oscillating system is the internal capacity of the cathode-heater combination. The inductance is that of the leads combined with that of the center-tapped resistance. This resistance unit actually has enough inductance to be troublesome at the very short waves. The cure consists in merely adding a capacity across one side of this center-tapped "inductance" so as to kill the resonant combination.

There are two of these cathode-heater oscillating circuits. One is in the

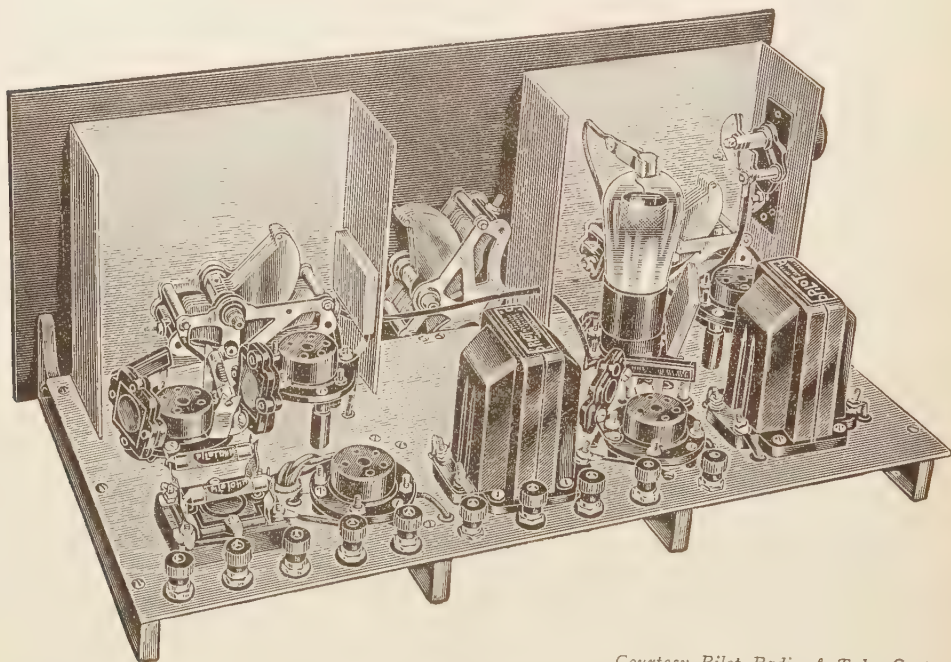
the wavelengths are longer. As a further clue to their cause, they do not occur until the plate and grid connections are made for the screen grid tube. They exist in these leads and are obviated by the insertion of the .2 mf. by-passing condensers and the small chokes as shown in Fig. 171C. The chokes are commercial, cylindrically wound resistors; but their main function in the plate and screen grid leads is a choking one. They are indicated in the sketch as 450 ohm resistors.

There is another point of special interest about the design of this set. The ordinary regenerative receiver "squawks" at the very point of oscillation. It is most annoying not only because of the objectionable noise, but because that particular point is the one at which signals are most likely to be heard since the detector tube is in its most sensitive condition. It can be completely subdued by using a high resistance in the plate circuit of the detector as shown in Fig. 271C. There appears to be a highly critical condition existing in the grid circuit at the starting point of oscillation. Just as the grid tends to change from the slight positive bias, which it normally has, to the negative value which the rectification gives it, it undergoes an oscillatory condition which causes a bad "squawk" when the plate voltage is fed through a transformer. But when the plate potential is supplied through a high resistance such as the 0.5 megohm shown in the figure, the effective plate voltage drops when this condition occurs and this decline immediately stops the oscillation or "squawk." This makes the detector go into R. F. oscillation in a very smooth manner, permitting almost perfect regeneration on even the weakest stations.

354. **PRACTICAL A. C. TUBE ELECTRIC S.W. RECEIVER:** Fig. 171C shows the complete circuit diagram for an A.C. tube electric short-wave and broadcast band receiver designed to eliminate all of these troubles. A careful study of this diagram will reveal how the various by-pass condensers, etc. are connected. "C" bias voltages are obtained in the usual way by means of resistors placed in the cathode circuits of the heater type tubes. The actual receiver is shown in the photograph of Fig. 271D. The R. F. and detector stages are completely shielded by aluminum shields. Only half of the detector and R. F. shields are shown in place in order to reveal the parts inside. Regeneration is controlled by the variable condenser in the plate circuit of the detector. The detector plate is connected to 135 volts. However, the tube itself actually receives far less voltage than this because of the drop of voltage in the 0.5 megohm plate resistor.

355. **SHORT-WAVE RECEIVER OPERATION:** The correct operation of short-wave receiving sets is usually learned only after considerable experience in tuning a particular set. Short-wave receivers should oscillate smoothly over the entire range of the tuning condenser, with each coil. If the set is correctly designed and the batteries (or socket power device) and tubes are in good condition, the fact that usually determines whether or not the set will oscillate, is the aerial series condenser. If the aerial is too long the set will not oscillate. Instead of cutting the aerial length, a midget condenser with a capacity range of from about 0.00001 to 0.00005 mfd. should be connected in series with the aerial. Different settings of this condenser should be tried at the various wavelengths, until the set oscillates smoothly.

Short-wave receivers usually work well with aerials about 30 to 50 feet long (including lead-in and ground wires). Longer aerials (75 to 100 feet) can be used for broadcast reception. It is important that all connections be well made and soldered. The ground connection should be made to a cold water pipe or to a



Courtesy Pilot Radio & Tube Corp.

Fig. 271D: A.C. Super Wasp S. W. and Broadcast Wave Receiver With Shield Cans Partly Removed

separate pipe buried in moist earth. The importance of good ground connections cannot be overstressed, as they are responsible in a large measure for the good or poor results obtained with a receiver.

There are two methods of tuning-in broadcasting stations with a regenerative receiver. This includes both short wave receivers and broadcast band receivers.

Starting at zero on the dial, turn up the tuning condensers slowly with the left hand, and keep the set oscillating by manipulating the regeneration control with the right hand. When you run into the signals of a broadcasting station you will hear a whistle or "rushing" sound mixed in with badly distorted music or voice. You hear this mixture because the incoming signals are beating or "heterodyning" with the oscillations produced locally in the receiver. To clarify the signals, turn down the regeneration control very carefully, at the same time twisting the vernier dial back and forth a fraction of a degree to keep the tuning accurate. The music should clear up just as the whistle disappears. If the music disappears *with* the whistle, or becomes too weak to be understandable, you will have to try the second method, which is known as "zero beating." This is always the best

method for bringing in weak signals, although it requires some experience in tuning.

With the foregoing method, you hear a whistle because the frequency of the broadcasting station's carrier wave is just a little different from the frequency of the oscillations generated by the receiver circuit. If you leave the set oscillating, but tune it with extreme accuracy to the *same* frequency as the incoming carrier wave, you will not hear a whistle, because the difference between the local and the incoming oscillations is zero, and no beat notes will be produced. However the voice and music impulses, which cause the carrier to wobble slightly, will come through, and you will be able to distinguish the program. The signals are likely to be somewhat distorted, but this is not usually noticeable.

You can tell when you are zero-beating a station by turning the tuning condenser a hair's breadth above and below the point at which the signals are understandable and clear of whistling. You will hear a whistle each time, as each time you move the condenser you change the frequency of the local receiver circuit and therefore cause a beat note to be set up.

Zero beating is an excellent means of fishing out very weak stations, because the receiver is in a very highly sensitive condition when it is oscillating.

Many weak and distant stations that you cannot hear at all with the set thrown just out of oscillation you at least will be able to identify if you zero-beat them.

Of course, in going after distant and foreign stations the time differences between the United States and the other countries of the world must be kept in mind. These have been given in the Chart in article 351.

REVIEW QUESTIONS.

1. What are the short radio waves?
2. Explain two peculiarities of short-wave transmission and reception.
3. Why must wiring and location of parts in short-wave receivers be done even more carefully in short-wave receivers than in broadcast band receivers?
4. Why are a number of plug-in tuning coils or condensers required to cover the short-wave band from 10 to 200 meters, whereas only one set of tuning coils and condensers are needed to cover the broadcast band from 200 to 600 meters?
5. Why is a tuning condenser of small capacity (about .00015 mfd.) usually used in short-wave receivers? Why not use a .00035 condenser with smaller coils.
6. Explain some of the design problems encountered in A.C. tube electric short-wave receivers. How can they be solved practically?
7. Describe the zero-beat method of tuning with a regenerative receiver.

CHAPTER 21

TELEVISION AND PHOTO-ELECTRIC CELLS

TELEVISION METHODS—PHOTO-ELECTRIC CELL—CELL CIRCUITS—NEON TUBE AND CONNECTIONS—TELEVISION PRINCIPLES—SCANNING DISC—COMPLETE TELEVISION SYSTEM—SCANNING DISC SYNCHRONISM—PICTURE DETAIL—APPARATUS—APPARATUS CONSIDERATIONS—RECEIVER—IMPROVED TRANSMITTER—PRACTICAL LIMITS IN TELEVISION.

356. **TELEVISION METHODS:** In the majority of the television methods in use at present, the scene to be transmitted is rapidly scanned by a photo-electric cell, acting as a sort of "eye," viewing in orderly succession each detail of it. The photo-electric cell converts these successive light impulses into varying currents which correspond to the differences in light and shade of the successive details. These varying currents are transmitted through space in the form of electromagnetic and electrostatic waves from the broadcasting station.

At the receiving station the received current produces at each instant, by means of a neon tube, a spot of light of a brightness corresponding to that of the detail of the scene which the photo-electric cell was observing at the moment it originated that particular current. At each instant the position of this spot of light is also caused to correspond to that of the detail of the scene. The entire scene in successive details is thus reproduced for an observer.

Before continuing with a description of television by one of the common methods at the present time the photo-electric cell and neon tube will be studied.

357. **PHOTO-ELECTRIC CELL:** It has been found that some metals give off electrons when they are exposed to the action of light. Potassium and many of its compounds give off electrons when exposed to light in the visible part of the spectrum. Zinc does not give off many electrons when exposed to ordinary light, but gives off electrons quite rapidly when exposed to light of short wavelength, such as ultra violet light. This effect is known as the photo-electric effect.

Under ordinary conditions, when the surface of the metal is exposed to the air, the emission of the electrons is interfered with by the presence of the larger air atoms. If the metal is put in a vacuum and a beam of light is then allowed to fall on it, the electrons are free to be thrown off into the space surrounding the metal, and the number of electrons emitted per second is proportional to the intensity of the light applied.

If some kind of an electrode kept at a positive potential is put in the vacuum with the illuminated metal plate the electrons may be collected on this, and a plate current will flow, as in the case of a vacuum tube. The electrons will continue

to be given off and the current due to them will continue to flow just as long as the light is shining on the metal plate. As soon as the light is cut off, the electron flow stops and the plate current also stops. The current flow will be proportional to the intensity of the light applied to the active metal plate.

A common form of photo-electric cell is shown in the photograph of Fig. 272. A simple circuit diagram is shown in Fig. 273. The inside of the glass bulb is silvered, and contact is made with the silver surface P by a sealed in platinum wire. The silver surface is coated with a thin layer of some material such as one



Fig. 272. Photo-electric cell

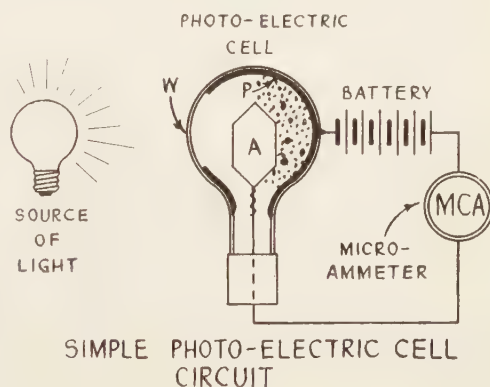


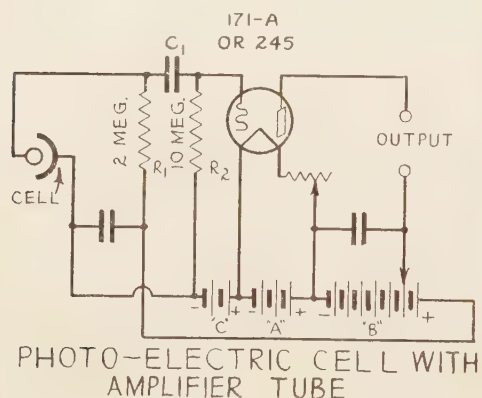
Fig. 273

of the alkali metals, lithium, sodium, potassium, rubidium and caesium, which are particularly photo-sensitive. This takes the place of the metal plate mentioned. The other electrode, A, projects through the base into the center of the bulb. A circular opening W (window) in the silver coating serves for the admission of the light.

358. **CELL CIRCUITS:** Fig. 273 shows a simple circuit which may be used to illustrate the fundamental action of a photo-electric cell. The source of light may be an ordinary incandescent lamp, and it will be found that the amount of current flowing in the milliammeter varies inversely as the square of the distance from the cell to the light sources, showing that the current increases or decreases directly with the amount of light falling upon the cell.

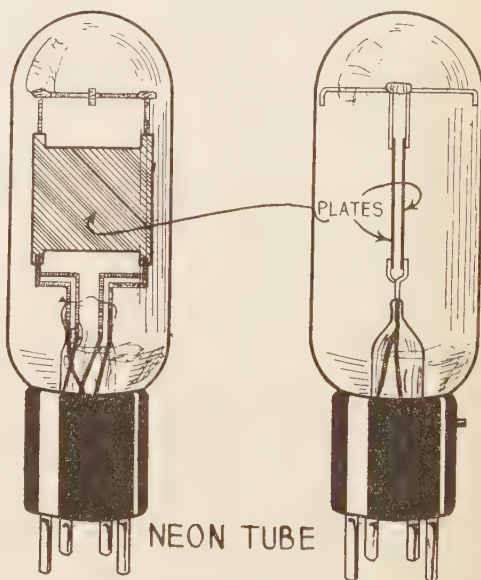
As the ordinary photo-electric cell does not pass sufficient current to be of much use in the direct operation of electrical devices such as television equipment, relays, etc., it is usually connected in the grid current of a standard vacuum tube and the current fluctuations due to varying light intensities are amplified by the tube. When the cell is used in this way, it is a source of variable potential rather than of current, as in this case only a "charge current" flows through the cell

and the potential acquired by one of the electrodes is proportional to the intensity of illumination. A practical circuit is shown in Fig. 274. First we have in the cell circuit a polarizing battery to draw the electrons from the sensitive material. A resistor R_1 is placed in the circuit and there will be a fall of potential across it. From this resistor the cell is coupled through a condenser C_1 and grid leak R_2 to a tube in the regular fashion used in resistance coupled amplifiers. This tube



Left: Fig. 274.

Right: Fig. 275—Neon Tube Showing Rectangular Form of Plates, and the Gap Between Them.



should be of as low a mu as possible when high frequencies are to be amplified. The tube can then be coupled to more tubes for further amplification, preferably by resistance coupling. As the light falling on the photo-electric cell varies, its plate current or internal impedance varies. This causes the voltage drop in R_1 to vary and this is communicated through C_1 to the grid of the tube, where it is amplified.

R_1 should be as large as possible in order to have a large voltage drop available. It must not be made too large, however, as then an appreciable variation in voltage drop will result and thus affect the positive potential applied to the cell and possibly produce distortion. A low value of R_1 helps the high frequency response on the tube end. Of course, all wires should be as short as possible and run free from other wires and apparatus.

From this first amplifier the impulses can be amplified in several successive stages to the desired extent. In television this is one of the difficult phases, because generally the initial impulses are so very small that an enormous amount of amplification is required, and tube noises become important. Also, as we shall see later, the amplifier must have a perfectly flat characteristic over a very large frequency range.

For applications outside of the field of television, a sensitive relay can be connected in the output circuit of the amplifying tube. This can be made to operate and close some external electric circuit whenever the light intensity changes in some predetermined way. Thus photo-electric cells can be made to turn a number of lights on or off, control the ringing of bells, etc.

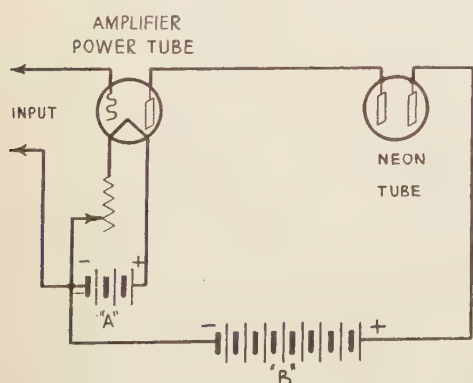
359. NEON TUBE: In order to receive television pictures by present methods, there is required a source of light which is capable of changing its intensity almost instantly with changes of potential in the receiver. This light reproduces the picture which is being transmitted, and its position in the circuit is comparable to that of a loud speaker in a broadcast receiver.

A gas-discharge tube of the neon type used for television consists of two large metal plate elements (Fig. 275) parallel to each other and mounted a small distance apart. The tube is filled with neon gas and is mounted on a standard UX tube base. When a potential difference is applied to the two plates, the neon gas around the plates glows with a pinkish color, the brilliance of the glow being proportional to the potential difference between the plates.

If a neon tube is connected to the loud speaker binding posts of an ordinary broadcast receiver it will convert the electrical energy into light vibrations instead of sound vibrations. The light emitted by the tube will vary with the varying electrical impulses sent through the receiver.

In television the purpose of the neon tube is to convert the rapid electrical impulses received, into corresponding light impulses. The familiar type of incandescent lamp (heated filament) would be entirely unsatisfactory for this purpose as it requires too great a length of time for a change in current to produce a corresponding change in the intensity of the light. The rapid current impulses in television work require that the light impulse device have no time lag.

360. NEON TUBE CONNECTIONS: The connection of the neon tube to the output tube of an amplifier can be accomplished in several ways. Fig. 276 shows one of the simplest but not the best method. The "B" battery or "B"



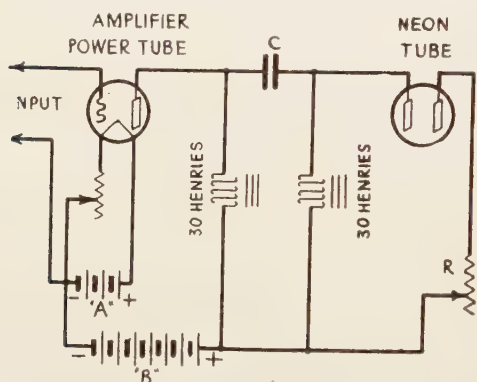
SIMPLE NEON TUBE CIRCUIT

Fig. 276

eliminator which supplies plate voltage for the power tube also provides the necessary potential for the neon tube. This is satisfactory providing the power tube does not draw more plate current than the rated current of the neon tube. The Raytheon neon tube is rated at 20 milliamperes D. C. For example the ordinary Raytheon neon television tube may be put directly in the plate circuit of a 171A tube which passes a plate current of 20 milliamperes, but is not usually put directly in the plate circuit of a 250 tube, which passes a plate current of 55 milliamperes.

The Raytheon Kino Lamp (neon tube for television) has an impedance of

1,200 ohms. The current passed through the tube should never exceed 20 milliamperes D.C., which corresponds roughly to a terminal potential of 200 volts D.C. In operation either terminal can be connected to the positive terminal of the "B" battery. When the tube is operating with D.C., a current-limiting resistor should be connected in series with the circuit at all times to prevent overloading. The plates in the tube are $1\frac{1}{2}$ inches square.



ANOTHER NEON TUBE CIRCUIT

Fig. 277

The circuit shown in Fig. 276 is simple, but it has one drawback. The impedance of the Kino lamp is considerably lower than the plate impedance of the tube (1,900 ohms in the case of a 245 tube and 1,800 ohms in the case of a 250 tube). The maximum undistorted power output of the power tube is rather poor with this impedance ratio, indicating the desirability of using either a choke and condenser output coupling or a transformer between the tube and lamp, providing one with a sufficiently good frequency characteristic can be obtained. In order to realize the maximum undistorted power output of which a 245 tube is capable, this

transformer should have a ratio which will cause the tube to see twice its own impedance in the plate circuit. This means an impedance ratio of $\frac{3800}{1200} = 3.1$ and

a turn ratio of $\sqrt{3.1}$ or 1.75. The transformer must, of course, be designed to have sufficient inductance to reproduce the low frequencies, without introducing in the winding sufficient distributed capacity to short circuit the high frequencies.

Fig. 277 shows another method of connecting a neon tube by means of a condenser and two 30-henry chokes. A resistance R in the neon tube circuit can be used to control the current through it.

361. **TELEVISION PRINCIPLES:** Television and motion pictures are made possible through a defect or failing of the human eye. The eye is slow and persists in seeing a moving object a perceptible length of time after the object has disappeared from the scene. This is sometimes called "persistence of vision." If a series of scenes is presented to the eye at the rate of at least 15 or 16 per second, the effect is that of a moving picture. This is also the principle employed in projecting "moving pictures" from a film.

In the usual methods of television the received picture is built up of a great many small dots or impulses of light, much the same as the dots of ink in a printed photograph. When halftone illustrations are made for printing purposes they are photographed through screens which are ruled at distances of from $1/60$ to $1/300$ of an inch apart, depending on the grade of the work. For newspaper work divisions of about $1/63$ of an inch are used, for magazine work divisions

from $1/110$ to $1/120$ of an inch are used. To the naked eye the picture thus made presents the effects of surfaces of light and dark grays over an unbroken area; but careful examination with a magnifying glass of the reproductions of photographs in this book, or in a newspaper (halftones) will show that they are composed of small dots, each occupying the same space and separated from its companion. Where these black dots are close together, the surface appears nearly black; where there are few black dots it is nearly white. When looking at the photograph from a short distance, the individual dots are not visible, but the effect of the entire picture as a whole is received. The detail of the reproduction depends upon the number of picture-elements used per unit area, that is, the fineness of the screen. This is shown in Fig. 277A. At the left is a reproduction of a photograph made through a fifty screen, i. e., 2500 elements per square inch; the middle picture is made through an 85 screen; the picture on the right is made through a 120 screen. A careful examination will show that the reproduction is really made up of a series of tiny dots. Notice how the detail of the picture is lost when a coarse screen is used, i. e., when the dots are spaced far apart.

The same principle is used in television. The screen before the television transmitter is broken up into similarly small scanning lines or slices and each is reproduced according to its corresponding brightness, in the same *relative position* at the receiver, so that the picture is reproduced with accuracy. If this is done at the rate of about fifteen times a second, a continuous moving picture results at the receiving end.

362. **SCANNING DISC:** The device which breaks up the image—"scans it"—at the transmitting end and puts it together again at the receiving end is known as the scanning disc, or Nipkow disc. It was invented by Nipkow in 1884. It is a disc with small holes arranged in the form of a spiral (Fig. 278). Each of these holes is as far from the next one as the width of the picture W , and the



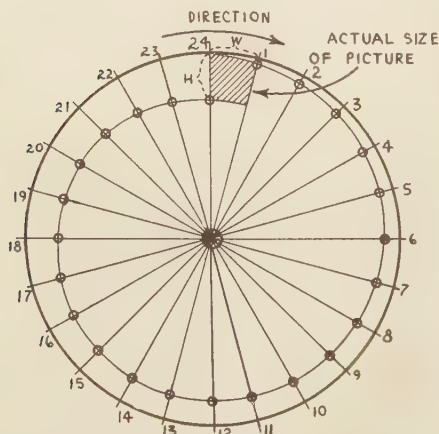
Fig. 277A—The Detail of the Reproduction Depends Upon the Number of Picture Elements Used Per Unit Area. Left: Made Through a 50 Screen, i.e., 2,500 Elements Per Square Inch; Middle: Made Through an 85 Screen; Right: Made Through a 120 Screen.

distance of each from the center of the disc differs from that of the next by the width of the hole itself. The pitch of the spiral is equal to the depth of the picture H. The layout of a disc for reception from a particular station depends upon various transmission factors of the station, as will be explained later.

363. **COMPLETE TELEVISION SYSTEM:** Fig. 279 shows a diagrammatic sketch of one form of a complete television system. We will follow the operation in detail, from the object to be televised, to the received picture.

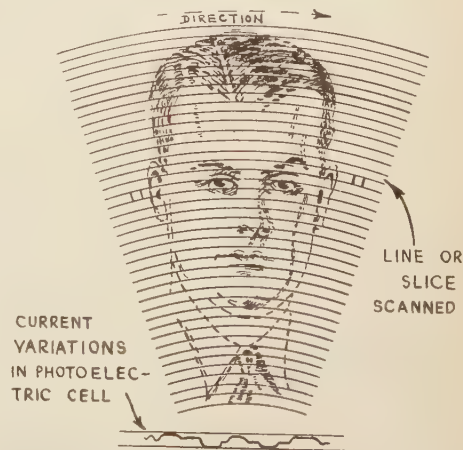
The object is illuminated by a powerful arc light or cluster of incandescent lamps. The light reflected from the object is collected by an adjustable lens which reduces the image to the size it is desired to transmit it. The rotating scanning disc is placed between this image and a photo-electric cell (or sometimes two or three cells). The hole in the disc which is farthest from the center crosses the image in a slightly curved line at the top (see Fig. 280). As it scans a horizontal slice of the image whose width equals the width of the hole, the light shining through on to the photo-electric cell at any instant sets up corresponding currents in the photo-electric cell. These varying currents are amplified greatly by the special amplifier and sent out from the station in the form of varying electro-magnetic and electrostatic waves. These are received at the receiving station, amplified by a special amplifier, and fed to the neon tube.

When this hole we are considering enters upon a part of the image which is bright, rays of light pass through into the photo-electric cell, which emits a throb of current. This is received at the receiver and lights up the neon tube.



SCANNING DISK 24 HOLES 20 R.P.S.

Left: Fig. 278
Right: Fig. 280



HOW PICTURE IS BROKEN UP
AND SCANNED

The scanning disc at the receiver is turning in exact synchronism with that at the transmitter. Just as the hole in the latter crosses the edge of the image, that at the receiver comes into position at the top of the plate of the neon tube,

and the observer sees a point of light which moves rapidly across the ground glass observation plate in the form of a slightly curved strip.

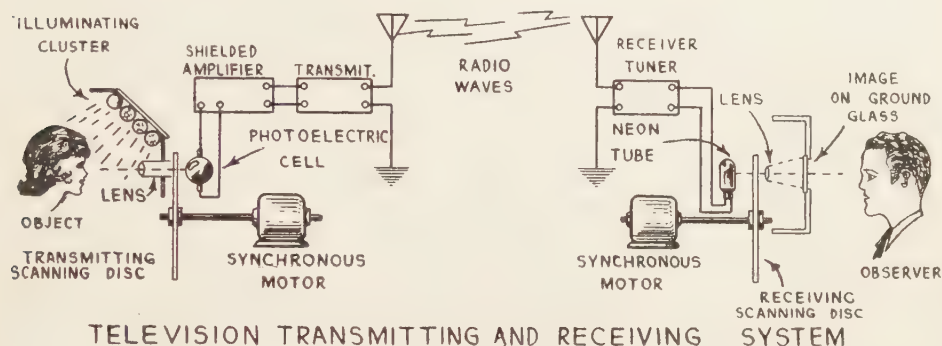


Fig. 279

When the hole in the transmitting disc comes to a dark spot in the image, the photo-electric cell stops its emission of electrons, the current diminishes, and the brilliance of the neon lamp diminishes proportionally. This process is repeated and the progress of the hole in the transmitter disc across the televised image is registered in a broken line of alternating light and darkness before the eye at the receiver.

At the instant the first hole clears the image at the transmitter (Fig. 280), the second one starts just below the first, and records the variations of light and darkness in a second line; this is repeated until the last hole has run along the bottom line of the image. If one of the photographs in this book were cut horizontally into a number of very narrow strips and they were pasted together end to end, we would have the picture decomposed into a single line of light and dark spots which, obviously, could be telegraphed or sent by radio. This is what the scanning disc at the transmitter does. The small graph at the bottom of Fig. 280 shows the variation of current in the photo-electric cell caused by such dark and light spots in the picture.

The scanning disc at the receiver, which corresponds with this exactly, is also passing an endless series of holes over the rapidly flickering neon lamp, each hole tracing a single line of alternating light and darkness, and the lines are so close together that the eye cannot see between them. The transmission is so arranged that every fifteenth of a second the picture is completed at the bottom, and the outermost hole starts at the top again to "paint" another picture, which the transmitter is beginning to send. Notice that the bottom of each picture is reproduced $1/15$ th of a second later than the top. As the successive pictures come at the rate of 15 per second, they are too rapid for the eye to follow, and persistence of vision makes them appear as a continuously moving picture, having the peculiar reddish tinge characteristic of the neon light. Some stations transmit a different number than 15 pictures per second.

364. **SCANNING DISC SYNCHRONISM:** Obviously it is absolutely essential that the scanning disc at the transmitting station, and that at the receiver run in exact synchronism with each other, and always be in the same relative position with it. If it does not there will be no picture, or only part of a picture. For instance, if the receiving disc was running at the same speed as the transmitting disc, but was one-half revolution ahead of it, then the picture would have dropped halfway down the screen. Slowing up the receiving disc would make the picture rise on the screen. Speeding up the receiving disc would make the image drop further.

It is difficult to secure this necessary synchronism. To aid in getting the receiver and transmitter in step (framing), it is customary to transmit first ahead of the figure a synchronizing signal, which in some cases results in a still geometric figure of simple design. This must be reproduced clearly at the receiver before an attempt is made with any moving images. When the figure is successfully received, it is evident that both discs are in step. Naturally it is extremely difficult to keep these separate discs rotating at exactly the same speed for any great length of time, and readjustments have to be made. A great deal of research is being done on the synchronism problem. The discs are driven by electric motors, usually of the alternating current synchronous or induction type.

365. **PICTURE DETAIL:** The fineness of detail of the reproduced picture depends on how many lines per inch the picture is broken up into when transmitted. The greater the number of holes used on the disc (each hole makes one line) the clearer the picture will be, if the holes pass the required amount of light to register on the photo-electric cell. The more holes we have, the smaller in size they are. Also as we increase the number of holes, we increase the number of impulses per second (frequency) which our apparatus must transmit and register, we increase the speed of response required of the photo-electric cell, and we increase the width of the radio channel required for transmission of the signals. This latter factor is one which is seriously handicapping the progress of television.

366. **APPARATUS CONSIDERATIONS:** The receiving scanning disc is usually made of metal, aluminum or brass and thick enough to be rigid. The speed of the disc is always determined by the number of pictures sent per second by the station which it is desired to receive. The receiving projector can be arranged to give any size picture desired, limited only by the size of the illuminated plates in the neon tube used. The Raytheon Kino lamp with $1\frac{1}{2}$ inch square plates will successfully cover a picture image about $1\frac{1}{4}$ inch square. A magnifying lens can be put in front of the viewing plate. This will enlarge the image, but it will also enlarge all the imperfections in the picture, thus decreasing the quality of the picture.

The spacing of the holes in the spiral disc and the pitch of the spiral will determine what size picture is actually projected at the receiver. Thus, if the holes are spaced one inch apart and the inner hole is one inch nearer the center of the disc than the outer hole the picture will be one inch square. The spacing of the holes equals the width of the picture. The pitch of the spiral equals the depth of the picture. The size of the holes is automatically determined by the size of the

367. **RECEIVER:** For reception of the television signals any ordinary sensitive receiver with sufficient amplification and power output, ability to cover the proper tuning range, can be employed. It is preferable, however, to employ a straight resistance coupled audio amplifier in order to insure a flat amplification characteristic, for any slight distortion introduced by the amplifier makes its appearance as distortion in the received picture. Much less distortion can be tolerated in television work than can be tolerated in ordinary A. F. amplifiers. For this reason, transformer coupled amplifiers cannot be used. Fig. 281 shows



Fig. 281

the complete circuit diagram for a receiver, with constants for an amplifier of this type. This receiver was designed for experimental work on television. Fig. 282 shows a photograph of an experimental receiver for television.

368. **IMPROVED TRANSMISSION:** A schematic diagram of an improved system of television transmission is shown in Fig. 283. A very ingenious photo-electric pick-up system using four concave parabolic mirrors with small photo-electric cells in the focus of these mirrors is employed (see Fig. 284). The light from the arc lamp passes through the holes in the scanning disc. A lens system collects this light and projects it to the object to be televised. The light reflected from the object is collected by the four concave mirrors and in turn reflected on the small photo-electric cells. The amount of light finally affecting

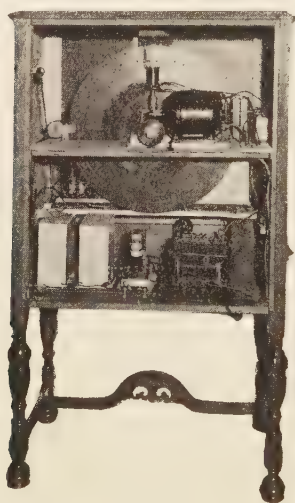
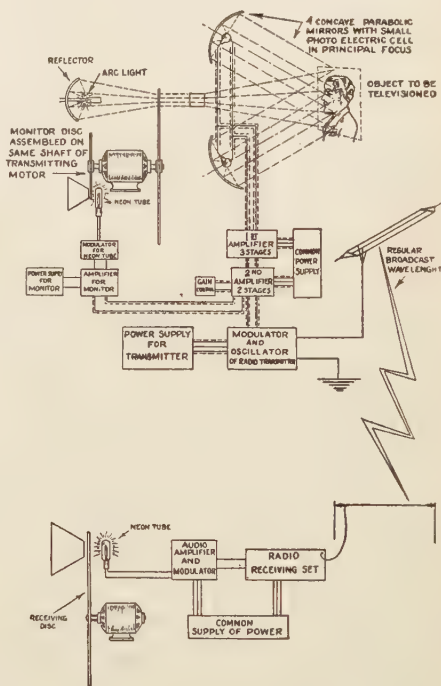


Photo Courtesy Pilot Radio & Tube Corp.

Left: Fig. 282—Experimental Television Receiver.

Right: Fig. 283—Improved Television Transmission System.



the small photo-electric cells is of the same order as if four large cells were used to pick up the reflected light from the image.

The advantages of this system are the ease of obtaining standard photo-electric cells of the smaller size, being able to achieve satisfactory results at a cost of less than one hundred dollars, compared to the fifteen hundred dollars necessary, using the large cells, and the securing of a more sharply modulated signal due to greater light and shadow photo-electric cell current variation.

The dotted lines in Fig. 283 indicate that all of the circuits so inclosed are most carefully shielded by inclosing them in metal conduits.

The photo-electric cell system is shown in detail in Fig. 384, which is a full front view of the top of this television transmitter panel exactly as it looks to a person being televised.

The photograph also shows the flexible copper cable shielding connecting the

four photo-electric cells in circuit. The shielded circuits include, of course, in addition to the photo-electric pick-up circuits, the circuits between the first amplifier, the second amplifier, and the modulator and oscillator of the radio transmitter (assuming the television signals are to be broadcast) and likewise, the circuits connecting all power supply units and to the separate amplifier used for the monitor scanning disc at the transmitter station.

The scanning disc of the transmitter is shown in Fig. 285, just to the left of the amplifier control panel, the disc being rotated by a synchronous electric motor.

The arc lamp and its housing is shown at the left of the illustration, the light from the lamp passing through the holes in the scanning disc, a lens system, and finally reaching the subject to be televised.

The design of the scanning disc itself is of extreme importance, for upon it depends the frequency of the transmitted signals as well as the definition or degree of perfection of the televised object or picture.

Fundamental improvements were incorporated in the scanning disc used in the circuit being described, particular attention being given to the size and shape of the holes in the disc.

The amplification of the original photo-electric energy at the transmitter as well as at the television receiver is a serious problem, particularly from the point of view of reducing the noise level, because five or six stages of audio frequency amplification must be used over a wide band of audio frequencies and at the same time the phase relationship of the final output current must be kept practically at zero with respect to the original input current, over the entire frequency band.

369. PRACTICAL LIMITS IN TELEVISION: Present methods for transmission and reception of pictures are by no means perfect. They have very definite limitations, and it is entirely possible that practical television of the future will operate on entirely different principles.

In order to produce a really good picture (halftone) provision must be made to reproduce about 150 changes in light and shade per inch. This same division is required up and down in a vertical direction as well as along the horizontal. That is, the picture must be made up of 150 times 150 or 22,500 dots per square inch, in order to produce fine detail. If the detail is to be at least as good as that in the photographs of newspapers, a division of about 50 dots to the lineal inch

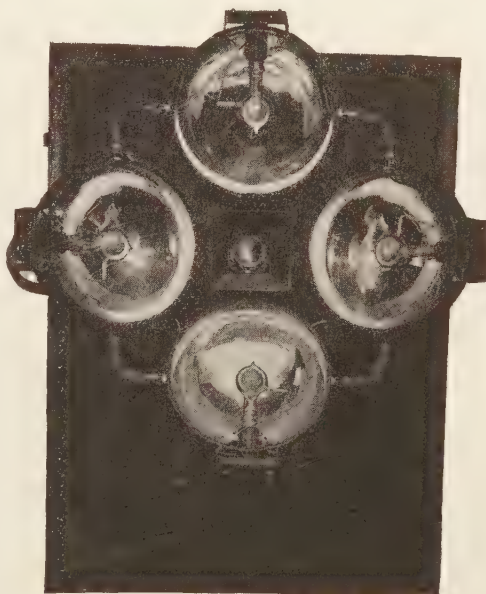


Photo Courtesy Pilot Radio & Tube Corp.

**Fig. 284—Photo-Electric Cell Unit
of Transmitter of Fig. 283**

must be used or $50 \times 50 = 2,500$ dots per square inch. That is, 2,500 dots or electrical impulses must be transmitted for each square inch of picture. To get the present small sized pictures one inch square, if pictures were transmitted at the rate of one per second, there would be 2,500 dots transmitted per second. If ten pictures per second are transmitted, the last dot must arrive within a tenth of a second after the first dot, so the rate of transmission over a single waveband would be 25,000 dots or impulses per second. The highest frequency which must be transmitted to get good quality may be taken as equal to about half of this figure or 12,500 cycles, for it is rarely the case that any scanned slice of a picture will contain a series of dark dots which are all spaced at different intervals.

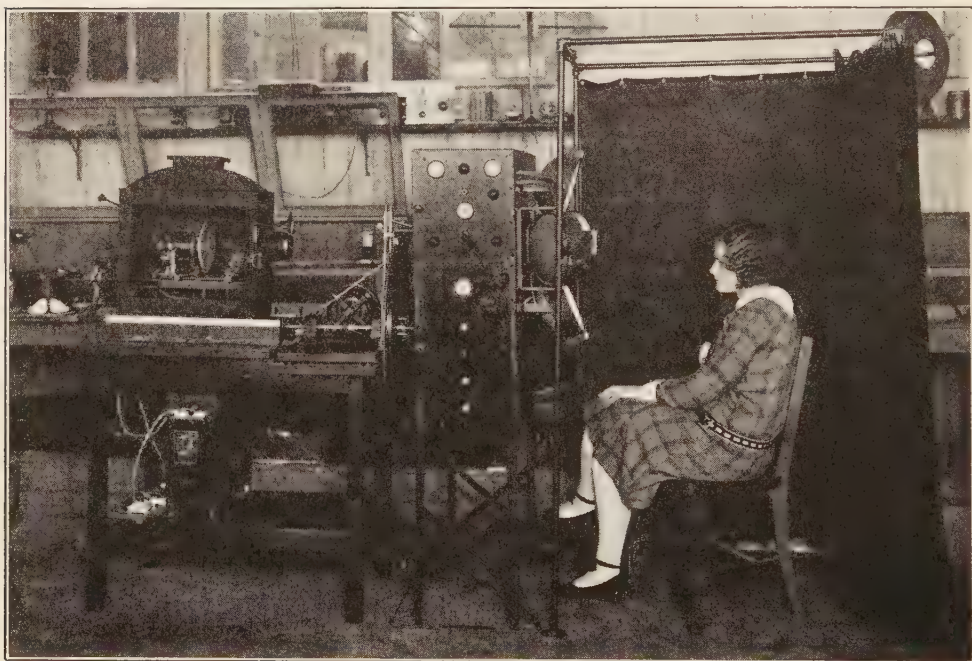


Photo Courtesy Pilot Radio & Tube Corp.

Fig. 285—Complete Television Transmitting Apparatus. Note Arc Lamp House at Left.

A station transmitting within the broadcast band, under present laws, is limited to 5,000-cycle modulation, making a carrier wave with two sidebands each 5 kc. wide or a total width of 10 kc. Therefore, any broadcasting station transmitting television programs and using a number of lines and number of pictures per second such that requires a frequency band greater than 5,000 cycles must either modulate above the limit allowed by the law, or suppress in the amplifiers the frequencies above 5,000 cycles. The latter procedure is being followed out in most cases at present, resulting in loss of detail in the pictures.

The table below shows how the value of the highest frequency which should be transmitted varies with the number of pictures per second and the number of scanning lines. For example, a 50-line picture, sent 15 times per second, requires up to 19,000 cycles. Scanning discs having 48 holes and rotating at a scanning speed of 15 pictures per second are in general use in present experimental television work.

No. of Lines	No. of Pictures Per Second		
	10	15	20
25.....	3,100	4,700	6,000
50.....	12,000	19,000	25,000
75.....	28,000	42,000	56,000
100.....	50,000	75,000	100,000

Since the total frequency range existing in the short-wave region from 5 to 200 meters is very large (58,500 kc.), it seems at the present writing that future television work will be carried on at the short wavelengths, if a large number of television stations are to be accommodated on the air. As was explained in Article 345 in Chap. 20, the 200-600 meter broadcast band covers a frequency range of only 1,000 kc. (see also Appendix).

The circuits and equipment shown in this chapter were included merely to give the reader an insight into how the television transmission and receiving problem is being attacked and worked out. It is probable that if commercial television ever becomes a practical reality, the apparatus used may differ in design or even in principle from that described. Although some of the most able scientists in the world are working on the problem, the difficulties involved in making television practical are tremendous. However, we should not be too pessimistic about the outcome, for in this day of invention and research the impossibility of yesterday becomes the actual reality of today. The reader is cautioned, however, against believing all the claims made by inventors of various television schemes merely for fraudulent stock promotion purposes. Any one can find newspaper files in which television transmission and reception was reported to have successfully accomplished by practical apparatus as long as 15 years ago. Needless to say, the practical worth of these schemes is soon found to be zero.

REVIEW QUESTIONS

1. Explain the principle of "scanning" used in television work.
2. Explain the operation of the photo-electric cell.
3. Draw a circuit diagram for a single stage of amplification connected to a photo-electric cell.
4. Explain the operation of the neon tube.
5. Explain what is meant by "persistence of vision."

6. Draw a sketch of a scanning disc with 48 holes and ten pictures per second. The picture is to measure $1\frac{1}{4} \times 1\frac{1}{4}$ inches.
7. Why are resistance coupled amplifiers used almost exclusively in television work?
8. State several practical limitations of present forms of television systems.
9. What are the advantages of short waves for television work?

CHAPTER 22

SYNCHRONIZED REPRODUCTION OF SOUND AND SCENE (THE "TALKIES")

GENERAL CONSIDERATIONS—METHODS USED—VITAPHONE RECORDING SYSTEM—
VITAPHONE REPRODUCTION—SPEECH AMPLIFIER—NON-SYNCHRONIZED MUSIC—
SOUND—FILM METHODS—MOVIETONE SYSTEM—PHOTOPHONE SYSTEM—SPICING
FILMS

370. **GENERAL CONSIDERATIONS:** The rapid spread of the exhibition of talking moving pictures (commonly called "talkies") in theatres has aroused widespread interest in the methods employed in recording and reproducing the sound accompanying the picture. The fact that radio equipment in the form of electrical phonograph pickups, photo-electric cells, powerful audio amplifiers and loud speakers are used in this work makes a discussion of the principles involved and the methods used very appropriate here. A considerable amount of credit

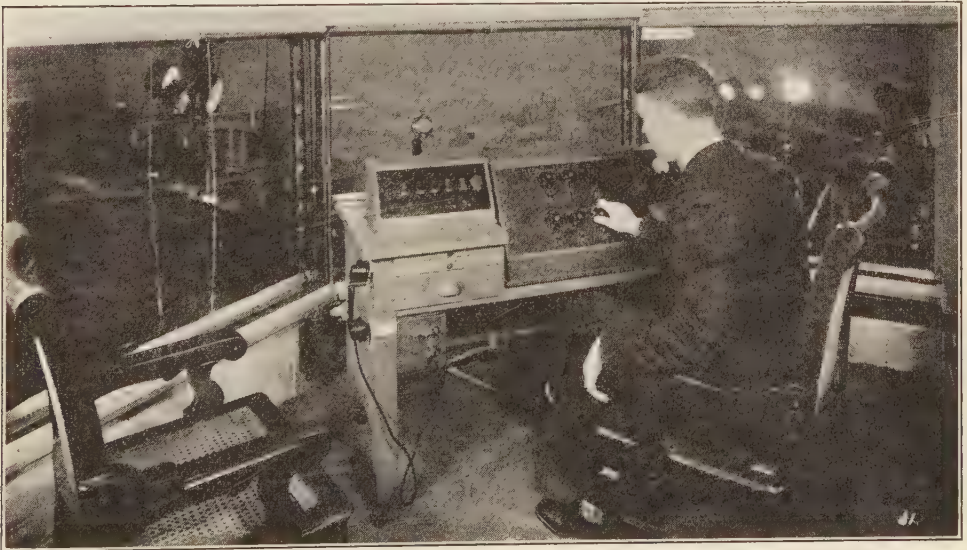


Fig. 286—The "Mixer Room" of United Artists Sound Film Studio

for the development of the "talkies" is due to the Bell Telephone Laboratories and associated concerns for their pioneer research work in the field.

371. METHODS USED: There are two fundamental methods which are used in practice to synchronize sound with moving pictures; first, that which employs a disc record similar to the familiar phonograph disc (Vitaphone System); and second, that which utilizes an optical record imprinted either along the edge of the motion picture film or in some cases, on a separate film run in synchronism with the picture (Fox Movietone, Phonofilm, and Photophone systems). The Vitaphone and Movietone methods were developed in the Bell Telephone Laboratories, and the Photophone by the Radio Corporation of America. All of them are being employed at the present time. They have practically revolutionized the motion picture industry.

372. VITAPHONE RECORDING SYSTEM: The principle of the Vitaphone system is to make a phonograph record of the sound simultaneously with the taking of the picture, and then play this record with a phonograph pick-up unit, amplifier and loud speakers while the picture is being projected on the screen. The sound is projected in absolute synchronism with the picture.

When the picture is being filmed the sound is picked up by several microphones located at advantageous positions in the studio. These feed into the mixing panel which is operated by a man located in a special glassed-in monitor or mixing room overlooking the scene of action (see Fig. 286). The operator views the stage upon which the action takes place through three thicknesses of glass to make the "mixer room" absolutely soundless. This is one of the most important parts of

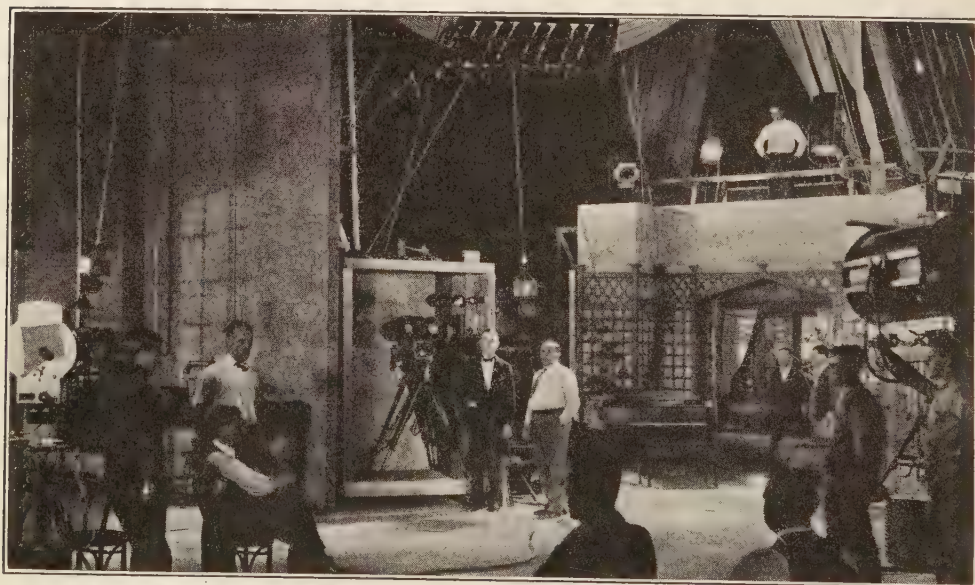


Photo Courtesy United Artists Studio
Fig. 286A—Directing Scene for Sound Picture

the sound apparatus in the entire circuit. The inputs of all the microphones are blended here and the operator can increase or decrease the input of any one micro-

phone at will. Thus he is able to "pull up" or "tone down" the voice of a star, the music from an orchestra, etc.

The director on the floor controls the recording, etc., by means of a signal box

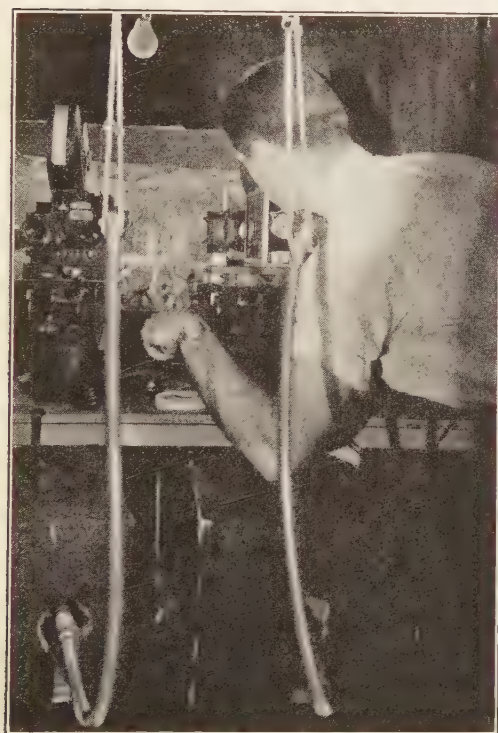


Photo Courtesy United Artists

Fig. 287—Camera Booth Showing Two Machines and Flexible Drive Shafts

which contains signal lights and push buttons for signalling the various stations concerned in the filming and recording. Fig. 286A shows a scene on a "set" in a sound stage studio just before the scene is "shot." All direction is done by motions of the hand or arm. In this picture all parts of the set are plainly seen. Three microphones suspended by ropes are plainly visible at various places on the set. The sound-proof camera booth, with one side removed to show the interior, can be seen in the center of the picture. The booth shuts off any mechanical noises produced by the camera as it cranks off the footage.

Every possible effort is made to prevent the pick-up and recording of undesirable noises during the filming of the scene. Arc lights in moving picture filming have given way to huge noiseless incandescent lamp bulbs, as the objectionable sputtering and hissing noises of arc lamps would be recorded along with the rest of the sounds. The cameras are placed in soundproof booths with padded walls and thick glass windows. The camera

driving motors are covered, and drive the machines by noiseless flexible shafts. This is to prevent pick-up of the camera noises by the microphones. Fig. 287 shows a camera booth with two machines installed.

The studio in which sound pictures are recorded must be either sound-proof or acoustically treated, so that sounds from outside do not penetrate, to be picked up by the microphones within the studio and thus interfere with the sound record being made. The interior of a sound-recording studio is acoustically treated so that it will not be too reverberant and thus effect all sorts of reverberation, echo and extraneous sounds.

Sound energy once produced in a studio will continue to exist until it is absorbed and this rate of absorption will be very low if the studio is surrounded by hard-reflecting surfaces. If not acoustically treated, it is possible that the rate of absorption within a studio would be so low that a word spoken in a usual tone of voice would be heard for several seconds afterwards, which would mean

that the dozen or so syllables following the word in question would blend into the decaying sound of the word and render understanding extremely difficult.

On the other hand, a sound-recording studio should not be too dead. It should have some life to it. The life of a studio is a function of the walls surrounding the studio, the ceiling, the floor, and the persons and articles within the studio. When a sound shot is being made, it is obviously desirable to pick up only the sound pertaining to the action being filmed and all extraneous noises only aid in bringing up the ground noise and are, therefore, a detriment to high-grade recording.

From the monitor room, the signal currents are fed to powerful four or five stage audio amplifiers which greatly increase their strength.

Then the currents are fed to the mechanical recorder which cuts the record. The "wax" records used in the Vitaphone method are "laterally" cut, i. e., the

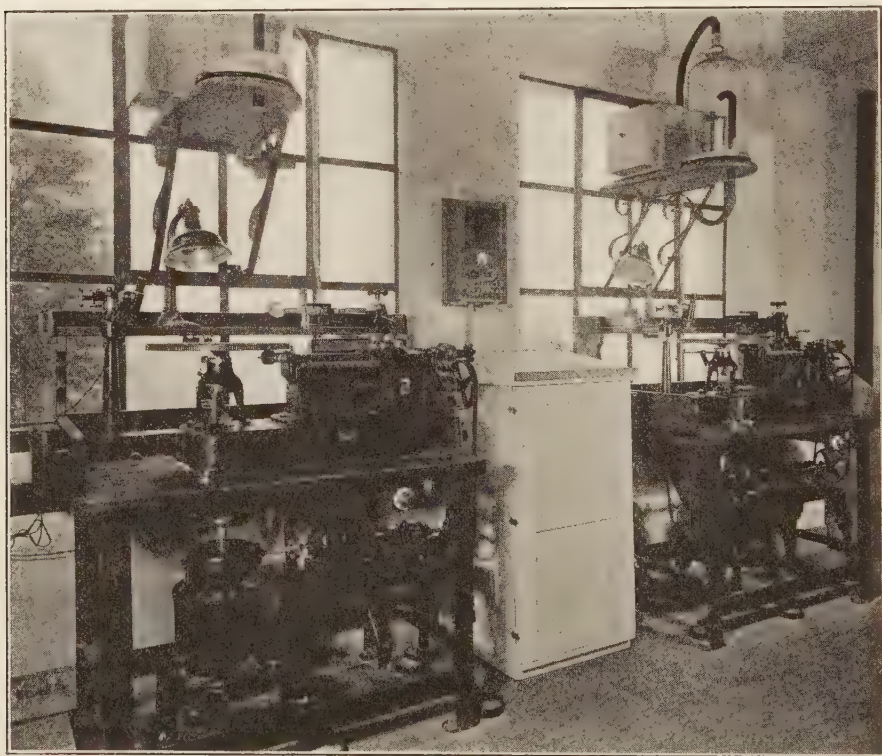


Fig. 288—Disc or "Wax" Recording Machines in Recording Room of United Artists Studio in Hollywood

groove is of a constant depth and oscillates or undulates laterally about a smooth spiral. The cut is about 0.0025 inches deep and 0.005 inches wide. The space between grooves is about four mils. (0.004 inches). The number of grooves per inch varies between 80 and 100 in usual practice. The linear speed of the

record past the cutter (or reproducing needle) varies between 70 and 140 feet per minute. Recording is accomplished by a cutting stylus which is made to vibrate in strict accordance with the energizing current.

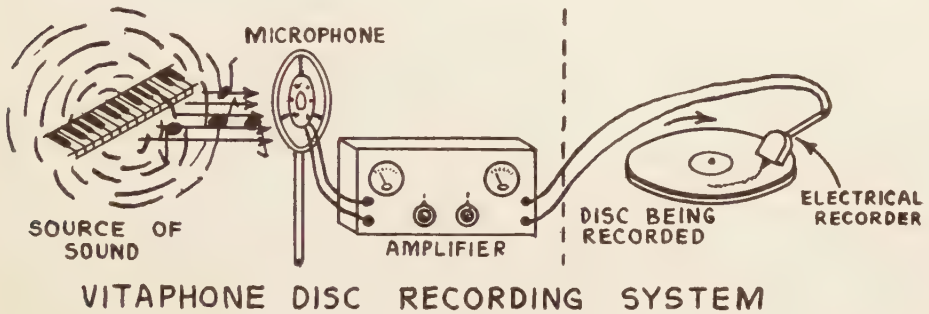


Fig. 288A

Fig. 288 shows the recording room in which two recording "disc machines" developed by the Bell Telephone Laboratories are located. They are constructed to be mechanically rigid and are arranged to be driven synchronously with the cameras. The turntables upon which the "wax" record is placed may be seen at the left of each machine.

The original disc or "wax" as it is called, is of a metallic soap from 13 to 17 inches in diameter and about one inch thick. This is initially given a high polish and is then mounted horizontally on a turntable driven at a uniform rate of speed and synchronized with the film passing through the cameras. This synchronization is accomplished by electrical means of a highly technical nature. (For further detailed information on this subject the reader is referred to the Vol. 7 No. 3 issue of the Bell Laboratories Record). The cutting stylus cuts from the center toward the outer edge of the disc. The table rotates at about 30 revolutions per minute (which is less than one-half of the speed of the ordinary phonograph).

After the wax has been cut it is of course desirable to be able to "play" it at once in order to detect any flaws. For this purpose a special reproducer known as the "play-back" is used. This is made extremely light so as to produce no appreciable wear on the relatively soft wax record.

Ordinarily one machine contains a "play-back" disc which is used by the director in ascertaining if his record is as perfect as he wishes it to be as regards voice and sound. The other disc is the master disc from which the reproductions for the final picture are made. This arrangement is very similar to the process of making phonograph records. In some cases phonograph artists make from six to twenty wax discs before the perfect one is decided upon.

The glass jars above the machines in Fig. 288 form the depository for the wax shavings as the disc is being used, a suction process being utilized that sucks the small wax portions into the jar. These are emptied when the jar is near the filling point. A microscope is provided with each machine to enable the operator to carefully examine the recordings made.

If the wax is satisfactory it is then dusted with a fine conducting powder and electroplated, to produce a negative copy of the wax. This is called the "master." By successive electroplating steps, duplicates of the "master" known as "stampers" are obtained, from which large quantities of positive playing records can be made. A thousand or more pressings can be made from one single "stamper."

Great success is being attained in the perfection of methods for re-recording parts of disc records so that the material may be entirely re-arranged, portions being deleted or added. This of course is a great advantage for removing objectionable sounds for censorship purposes, etc.

An outline picture of the recording process used in the Vitaphone system is shown in Fig. 288 A. The sound is impressed on the microphone at the left which converts it into electrical current. These currents are amplified greatly by the audio amplifier and are then fed to the electrical cutter or recorder, which makes the impressions on the disc.

373. VITAPHONE REPRODUCTION: The Vitaphone records are supplied to the moving picture houses along with the respective picture films. In the projecting booth a horizontal turntable is mounted beside each projection machine as shown in Fig. 289. This table is rotated by the same motor which drives the film through the projector so that, if the operator sets the needle of the phonograph pick-up unit at a marked point on the record coincident with threading a marked portion of the moving picture film over the driving sprocket, then perfect synchronism between sound and picture will be maintained.

The pick-up is usually of the electro-magnetic type, of refined design so as to produce good fidelity over a wide range of frequencies. The frequencies reproduced by the commercial systems range from about 30 to 6000 cycles. The picture film and sound record are started together and have the same playing time. There is a separate record for each reel of film.

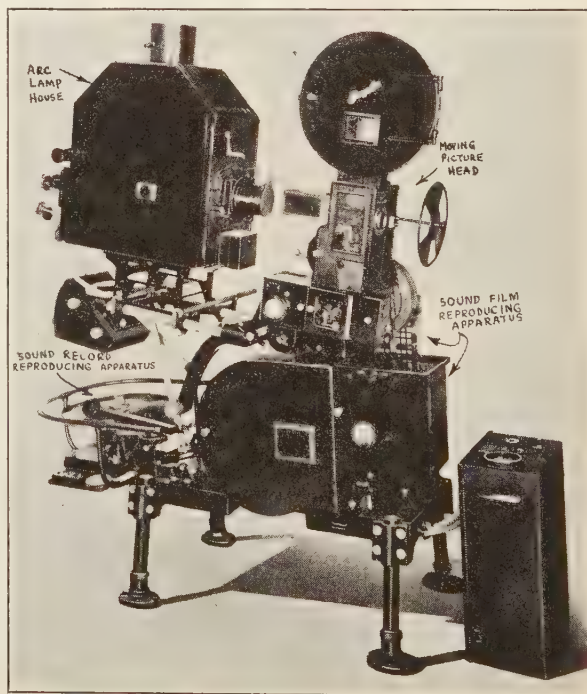


Photo Courtesy Bell Telephone Labs.

Fig. 289—Projector With Reproducing Apparatus

As with ordinary motion pictures, two or more projectors must be used alternately to present a continuous program. At the end of a record the music or speech coming from one machine must be blended imperceptibly into that from the other just as the picture from one reel is faded into that from the next. At a

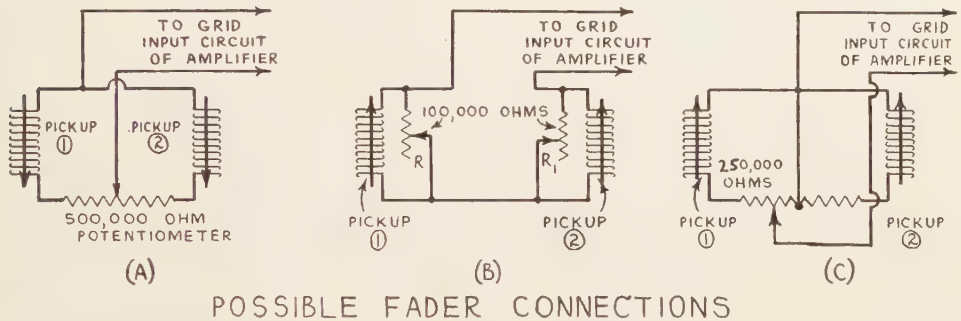


Fig. 290

given spot in the picture the second machine is set in motion. Immediately thereafter the "change-over" is made. This is done on the screen by closing the iris shutter of the expiring projector and instantly opening the shutter of the new machine. The change-over between the two sound records is accomplished by a device known as a "fader."

At the end of each sound film or disc the music overlaps that at the beginning of the next. As the starting projector goes into operation the fader knob is turned and the current coming from the expiring record is reduced to zero and the response from the new record is brought up to any desired level.

The fader usually consists of one or more potentiometer resistances suitably connected. Fig. 290 shows three possible "fader" connections, for feeding pick-up units directly to the grid input circuit of the amplifier. The arrangement shown in Fig. 290A is workable, but it acts as a series resistance and does not entirely eliminate the signal from one pick-up when in the "full" position for the other. The circuit of Fig. 290B gives a controllable degree of mixing but has bad frequency characteristics when one resistor is not in the full "off" position. It is also inconvenient as it requires that two separate resistors be operated simultaneously. Fig. 290C shows a better way, as it operates as a voltage divider, can be controlled with one hand, has a good frequency characteristic, and entirely eliminates the signal from one pick-up when in the full "on" position for the other. The device consists of a standard 250,000 ohm potentiometer with a fourth fixed contact made to its exact electrical center. (If it is desired to match impedances, the load into which each pick-up is terminated should have a value approximating the impedance of the pick-up used.) The change-over from one reel and record to another is barely perceptible to the audience when done by a skillful operator.

Faders supplied with Vitaphone installations are so designed that in the lower range used in changing between projectors, the steps are rather large, whereas in the upper range the volume changes in scarcely perceptible steps. The fader

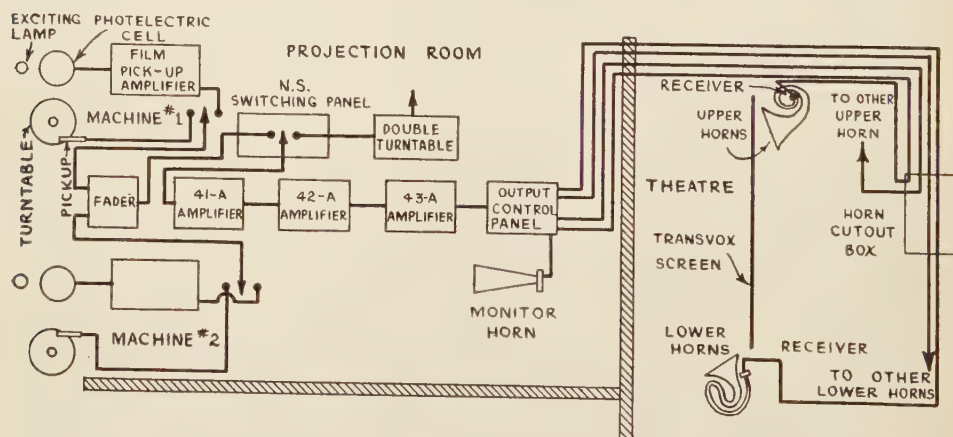
can thereby be used as a volume control and also for equalizing the level of sound obtained from different records. As the acoustical characteristics of a theatre, due to its dimensions, architectural features, and especially the size of the audience, varies considerably from time to time, the fader serves also as a convenient means of controlling the volume of the reproduced sound in order to obtain the most natural and pleasing reproduction.

After passing through the fader the sound currents go to a series of special amplifiers, where they are enormously intensified. These amplifiers are designed so that all frequencies from about 40 to 10,000 cycles are amplified about equally.

The amplifier is usually built in three units. The first consists of a three-stage resistance coupled amplifier using low power tubes with their filaments energized by a 12 volt battery. The second unit consists of a push-pull stage of medium power tubes heated by alternating current, while the third unit consists of a push-pull stage using high power tubes with filaments energized by alternating current. Plate potentials for all tubes are obtained from rectified alternating current supplied by rectifier tubes.

For small theatres only the first two units are used, while for large theatres one or possibly two of the third type are also used to obtain sufficient volume of sound for the auditorium without overloading. The three units are capable of multiplying the energy of the reproducer nearly one hundred million fold.

The output of the last amplifier is brought to an output control panel consisting of an autotransformer having a large number of taps which are connected to a number of dial switches. The loud speakers are connected to these switches so that the impedance of the amplifier output can be matched to the number of



SOUND PICTURE INSTALLATION IN THEATRE

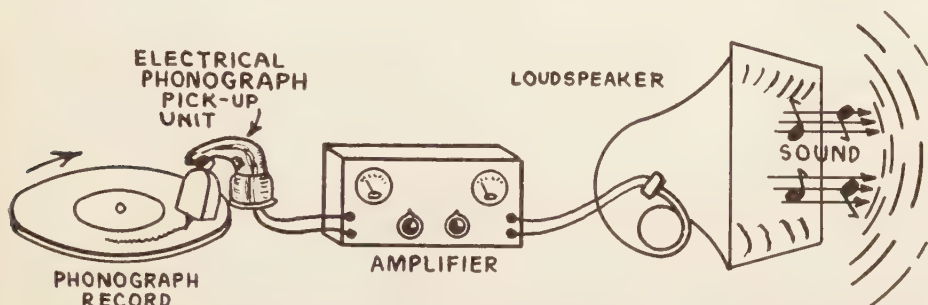
Fig. 291

Courtesy Bell Laboratories

loud speakers it is desired to use at any time. This makes the individual adjustment of volume of any loud speaker possible when necessary.

A usual theatre installation consists of four loud speaker horns placed at

the front of the theatre. Two of these are placed in the orchestra pit and directed more or less toward the balconies, while the other two are located behind the upper edge of the screen and directed downward towards the rear floor seats. There are several elemental factors which govern the location of the loud speaker in the theatre. One of these is what may appear to be a lack of synchronism



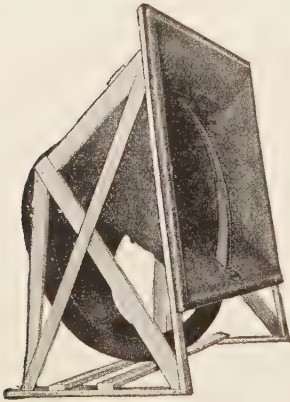
SOUND REPRODUCTION FROM DISC RECORD IN VITAPHONE SYSTEM

Fig. 291B

between the moving picture and the sound; that is to say, the ear may subconsciously detect a fraction of a second difference between the movement of the actor's lips and the reception of his voice. This is not a technical defect but a perfectly natural law that governs the difference between the speed of light and the speed of sound. Now the movement of light is practically instantaneous (186,000 miles per second), so that the man sitting in the farthest row of one of our great theatres actually sees the image on the screen at the exact instant that it appears on this screen, while the sound, coming the entire length of the theatre, strikes his ear a fraction of a second later, since it moves at the rate of only 1084 feet per second. The natural reaction to this is to wonder why loud speakers could not be placed in all the different parts of the theatre. However, a careful analysis of this suggestion will make the drawbacks self-explanatory. A cure of this kind would be worse than the original ill, due just to this very time lag. The spectator in the far row would hear the sound from the speakers in the rear of the theatre at exactly the same time that he would see the image, it is true, but, a fraction of a second later he would hear this same sound coming up from one of the speakers located in the front of the house. The result would be a fuzzy or blurred sound to every one in the house, as the spectator down front would also hear the response from the speaker located at the back of the house, as well as the speaker nearby. For this reason it has become almost standard practice to place all loud speakers at the front of the theatre, and facing out toward the audience. Fir. 291 shows a typical installation of equipment for sound pictures. The long horns used (about 14 feet) are of the exponential type with electro-dynamic units. One of these folded exponential horns is shown in Fig. 291A. The directive sound characteristic of the particular horns used is important since it is responsible for the illusion that sound comes directly from the screen.

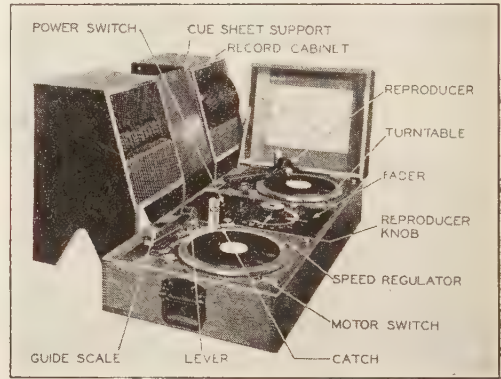
If speakers which radiate their sound over a wide angle were used, the sound would appear to be coming from a point some distance behind the screen. A special type of screen, reflecting light well but transparent to sound, is used for the picture so that the sound from the speakers located behind the screen is not seriously interfered with.

A small monitoring horn is placed in the projection booth for the convenience of the operators so they can follow the program continuously and instantly detect any trouble in the reproducing system.



Courtesy Racon Elect. Co.

Fig. 291A—Exponential Horn Used in Theatres



Courtesy Bell Laboratories

Fig. 292—Non-Synchronized Music Equipment

An outline diagram of the sound reproduction process in the Vitaphone system is shown in Fig. 291B. The electrical phonograph pick-up playing from the record at the left produces varying electric currents which are amplified by the audio amplifier and then fed to the loud speakers, where the sound is reproduced for the audience.

374. SPEECH AMPLIFIER: In addition to its function as a part of the talking moving picture equipment, the sound projector system may also be used as a public address system for speech amplification. Microphones can be concealed in the footlights, and the horns so placed as not to affect them. For announcements ordinarily there is a microphone installed in the manager's office.

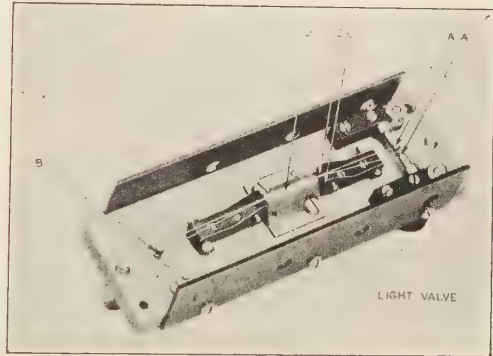
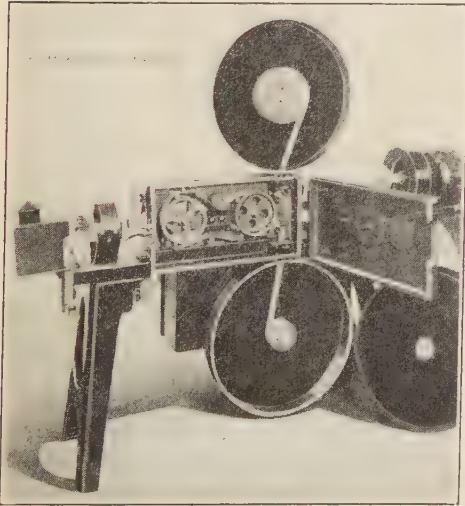
375. NON-SYNCHRONIZED MUSIC: By means of the auxiliary equipment shown in Fig. 292, the system can also be used to provide non-synchronized music as an accompaniment to ordinary pictures which do not have sound recordings. There is a cabinet containing two turntables each with a pick-up and means for locating it accurately on a record, and a fader to make continuous playing possible. The same amplifiers and loud speakers are used as for the synchronized speech and music.

376. SOUND FILM METHOD: There are two methods of sound film recording in general use. In the Movietone method the variations in sound are

produced by variations in light through a sound track of variable density and constant width along the edge of the film. The Photophone method produces the variations in sound by variations in the area of a uniformly dark film. In either case, the picture taking and projection are quite similar. The sound is reproduced by passing a sharply focussed beam of high intensity light through the projector during the course of reproduction, and due to the varying density or varying width of the sound track, the light coming through at the other side of the film varies in accordance with the variations in the sound track. This variable light is picked up by a photo-electric cell, which changes the light variations into variations of an electric current. The latter are amplified and applied to the loud speakers which change the electrical variations back into sound again. An outline diagram of this process is shown in Fig. 296C. The sound amplifying apparatus in the theatre is similar to that used with the disc record system with the exception of the pick-up unit.

377. **MOVIETONE SYSTEM:** In the Movietone system the film is recorded in the machine shown in Fig. 293. This is put in a sound-proof room near the "set." The microphones are connected to it. The recording machine is driven by a three-phase synchronous motor which is supplied with current from the same source as is the camera motor. These motors are electrically interlocked so that they are always driven at the same speed.

The heart of the recording machine is the light valve. The light valve consists of a loop of duralumin tape suspended in a narrow slit between two poles of an



Photos Courtesy Bell Laboratories

Left: Fig. 293—Movietone Film Recording Machine.

Right: Fig. 294—Light Valve.

electromagnet. When the amplifier output is super-imposed upon the steady magnetizing current the loop opens and closes in accordance with the current alterations due to the varying magnetic field set up. Fig. 294 shows this light valve. A duraluminum tape, 0.006 inch wide and 0.003 inch thick, is secured to windlasses A and A¹ stretched tight by spring-held pulley B. At points C and C¹

insulated pincers confine the central portions of the tape between windlasses and pulley to form a slit 0.002 inch wide, as it passes between the poles of the electromagnet whose armature is shown at D. The output terminals of the audio amplifier are connected to A and A¹.

Full modulation of the slit is accomplished when one side of the impressed A.C. opens the valve to 0.004 inches and the other side closes it completely. The valve is tuned to about 7,000 cycles to give the best frequency response.

If this appliance is interposed between a light source and a photographic film we have a camera shutter of unconventional design. Figure 295 shows a diagram of the optical system for studio recording. At the left is a light source, a ribbon-filament projection lamp, which is focussed on the plane of the valve. The light passed by the valve is then focussed with a two-to-one reduction on the photographic film at the right. The undisturbed valve opening appears on the film as a line 0.001 by 0.128 inch, its length at right angles to the direction of film travel. The width of this line varies with the sound currents supplied to the valve, so that the film receives exposure to light of fixed intensity during the varying time required for a given point to traverse the varying aperture of the slit.

Recording in the studio is carried out on a film separate from that which receives the picture. This practice permits the use of two machines to make duplicate sound records. The practice of separate negatives for sound and picture also permits the picture negative to be developed and printed according to well-established technique, and allows the necessary latitude in developing the sound record.

The recording machine is designed to draw the film from the upper feed magazine, past the valve slit, to the take-up magazine below. This is accomplished at a uniform speed of 90 ft. per minute by means of two sprocket wheels which engage the film perforations. Inside the left hand sprocket is a photo-electric cell which is affected by the light passing through the film so that its amplified current variations (see Fig. 274) may be heard from a loud speaker used to monitor the record as it is actually being shot on the film.

The light source, shown at the left of the machine, is an 18 ampere projection lamp with ribbon filament. Great care is exercised in adjusting so that the loudest sounds give the maximum allowable exposure. The program is rehearsed until satisfactory arrangements of microphones and amplifier gain is effected, this being judged by the monitoring loud speaker. An outline diagram of the Movietone system of sound studio recording is shown in Fig. 295A.

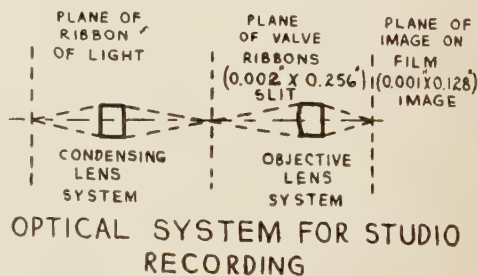


Fig. 295

The talking newsreels and photoplays released by Fox are usually recorded by a different method than that employed in other studios using film recording, since the heart of the system for changing the electrical current variations into

light variations which are in turn applied to the negative film, is a flashing lamp called the Aeolight.

The term "AEO" was derived from the three words, Alkaline Earth Oxide, by taking the first letter in each word. This seemed a fitting term to use because the coating on the negative electrode of this flashing lamp is an Alkaline Earth Oxide, and it is this coating which gives to the light the inherent properties which make it adaptable to sound pictures.

The Aeolight is a tubular-shaped lamp, about six inches long and one inch in diameter, inside of which there is a filament-shaped negative electrode and adjacent to this electrode there is a plate which is the positive electrode. The negative electrode, or filament is covered with barium and strontium, and the

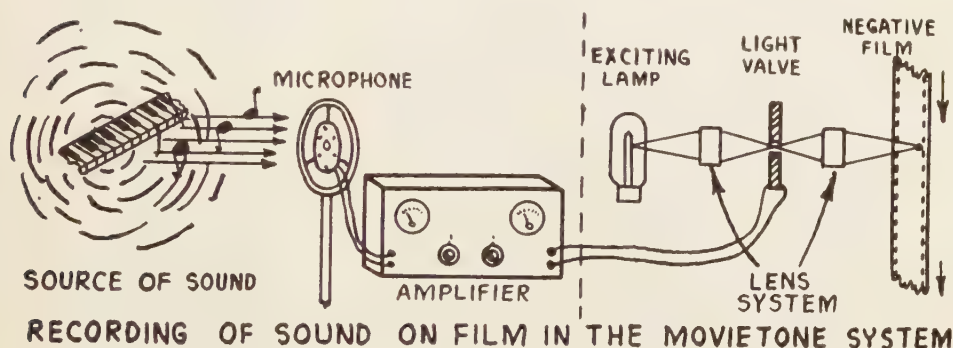


Fig. 295A

gaseous content of the Aeolight is about as follows: $1\frac{1}{2}$ per cent nitrogen; 3 per cent neon; and $95\frac{1}{2}$ per cent helium.

When about 350 volts, direct current, is applied across the "Aeolight," in series with 12,000 ohms, a bluish white glow is established within the tube. The D.C. voltage varies with different lights and is usually made of such a value that there will be a current of about 10 milliamperes flowing through the Aeolight circuit, because with a gaseous tube of this type, after the gap between electrodes has become ionized, the impedance of this path is liable to become lower and lower until it is practically a short circuit. The stabilizing resistor obviates this possibility.

When the Aeolight is energized with the D.C. voltage and normal direct current is flowing through its circuit, it is very sensitive to changes in voltage across its terminals; therefore, if the alternating current output from the audio amplifier is applied across the Aeolight terminals, it causes the brilliancy of the glow within the tube to vary in accordance with variations in the applied sound energy.

The Aeolight is placed in a tube in the back of the motion picture camera, the inner end of which tube has a minute slit, about 100 millimeters long and 1 millimeter wide, and it is through this little slit that light shines from the Aeolight

through to the film, which is passing the aperture in the end of the Aeolight tube at the rate of 90 feet per minute during the course of operation.

In the Fox-Case Movietone system of recording sound pictures used in newsreels, the action being recorded by the camera always bears a constant relation to the sound being recorded, because in this system the sound is recorded on the same negative that the picture exposures are made on and they are, therefore,

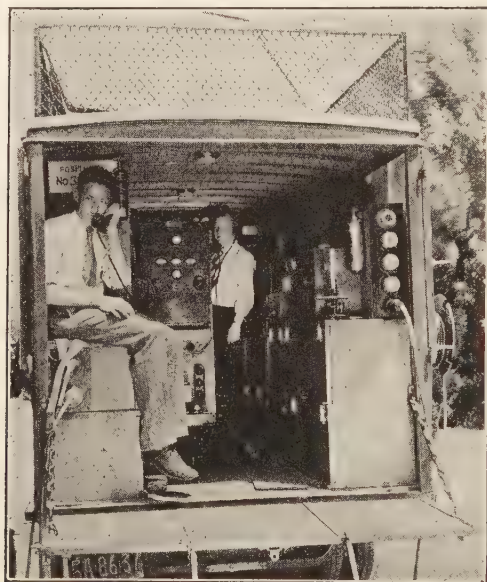


Photo Courtesy United Artists

Left: Fig. 296—Sound Truck for Outdoor Scenes.

Right: Fig. 296A—Strip of Movietone Film Sound Recordings.

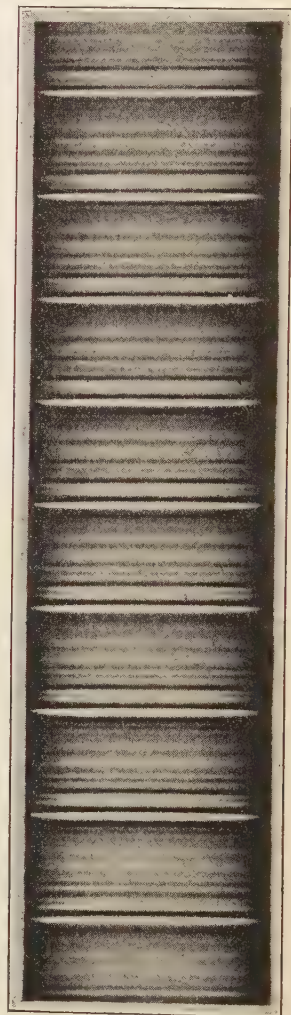


Photo Courtesy Bell Labs.

always in synchronism. The action is recorded at the front of the camera and the sound is recorded at the back of the camera through the medium of the aeolight, which is inserted through a tube in the back.

In the studios, the sound track is usually recorded on a separate piece of film, and the sound and picture are combined into a single print during the printing process, the picture being printed first, with the sound track masked out, and the sound track is printed last, with the exposed picture masked out so as not to fog it.

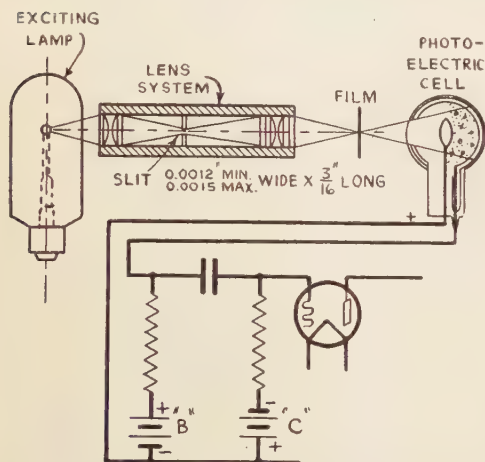
The Aeolight has the disadvantage of giving insufficient light to completely expose the film, and hence limits the amount of power which can be obtained in the reproducing system, without excessive surface noise, but has the advantage of being practically independent of frequency within the audio range.

Fig. 296 shows the interior of a sound truck employed by the United Artists studios in making outdoor scenes for talking pictures. Fleets of these units accompanying film companies to distant locations to record voices and sounds that synchronize with the photographic action.

The sound negatives made in the Bell Telephone Laboratories are on Eastman positive film. These are carefully developed and are then printed, marking the space needed for printing from the picture negative. The latter is then printed in combination with the sound record, which is similarly marked during the process. As the sound gate of the theatre projector is located $14\frac{1}{2}$ inches below the picture gate, in order that the sound record may be projected from a point which is in continuous motion instead of moving in the discontinuous manner necessary for pictures, the sound is displaced $14\frac{1}{2}$ inches ahead of the picture of the corresponding frame when printed.

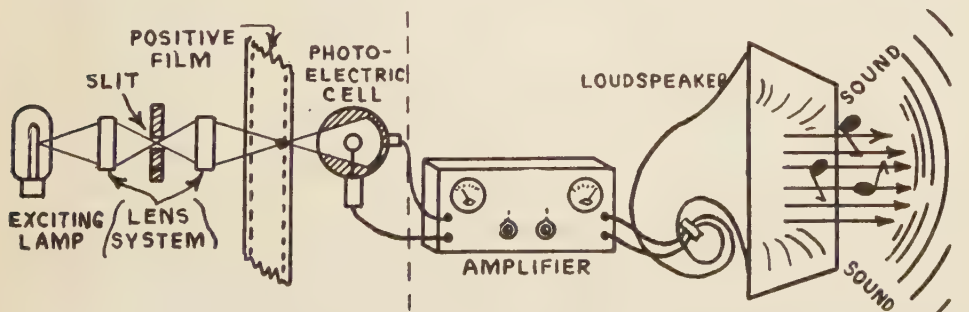
In practice it is found that the final print does not reproduce the higher frequencies as well as the lower, since the illumination of the film is .001 inches wide instead of being infinitely narrow. Thus an illumination due to an 18,000 cycle note completely extinguishes the note.

The picture of a section of Movietone film in Fig. 296A shows the sound track as a series of parallel black lines of different densities. To reproduce these



OPTICAL SYSTEM OF SOUND-FILM PROJECTION

Fig. 296B



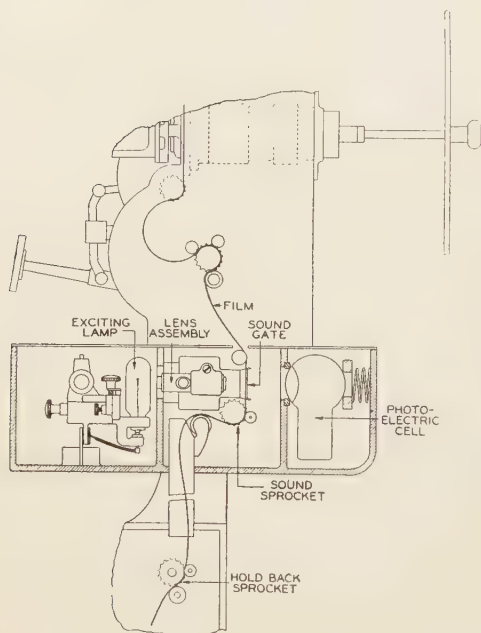
SOUND REPRODUCTION FROM FILM IN THE MOVIE-TONE SYSTEM

Fig. 296C

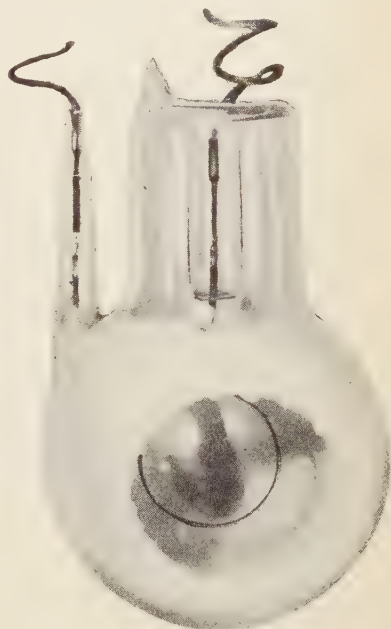
lines as sound, the general arrangement shown in Fig. 296B is employed. This sound-film reproducing unit consists of a sprocket for pulling the filament at a uni-

form speed past an aperture plate, an exciting lamp, a lens system, and a photo-electric cell. Light from a concentrated filament source is focussed by a condensing lens on a narrow slit as shown. An image of this slit is then focussed on the film by an objective lens, and light passing through the sound track on the film falls on the photo-electric cell.

As the photo-electric cell is properly polarized by the voltage applied, its output current is proportional to the light falling upon the light sensitive material in it. This current variation is amplified by several stages of amplification before



**Fig. 297—Motion Picture Projector
Equipped for Reproducing Sound
From Film.**



Courtesy Bell Laboratories

**Fig. 298—Photo-Electric Cell
Used in Bell Laboratories
Machine.**

being fed to the loud speakers. An outline diagram of the reproducing system is shown in Fig. 296C.

Fig. 297 is a diagram of a motion picture projector equipped for reproducing sound from film. Any change in the intensity of the sound is produced by a change in the density of the film. Any change in pitch is represented by the number of changes from dark to light and back again in a given length of the sound track.

This light falls upon a photo-electric cell such as shown in Fig. 298, and whose circuit diagram is shown in Fig. 274. The polarizing voltage is supplied to the cell through a very high resistance, across which is a voltage proportional to the light falling upon the cell.

378. **PHOTOPHONE SYSTEM:** In the R. C. A. Photophone System the recording is accomplished by an oscillograph whose mirror is actuated by variations in audio frequencies and intensities so as to throw a strong beam of light on to a moving film. These light variations, corresponding to sound varia-

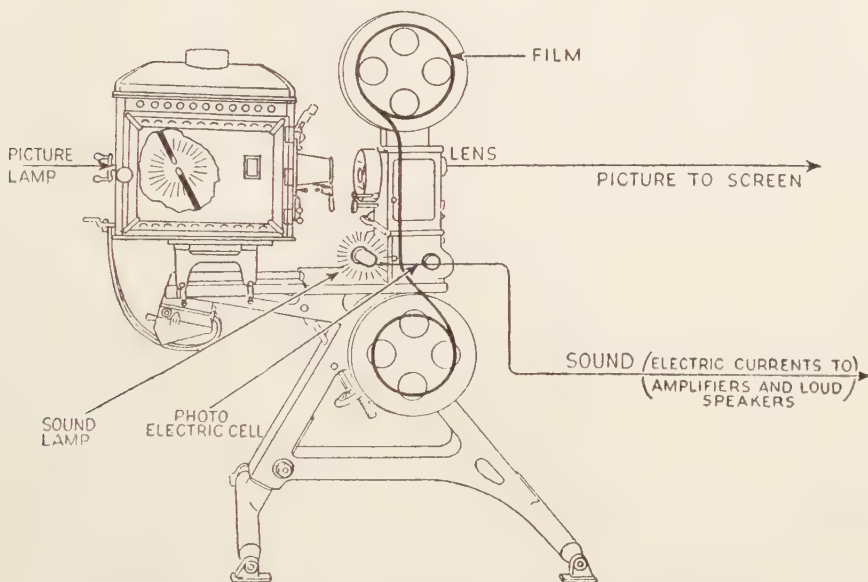
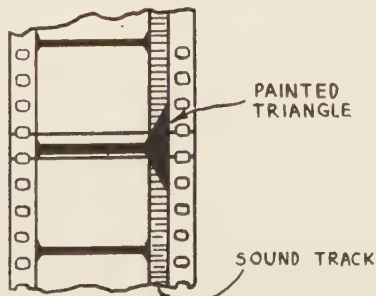


Fig. 299—Photophone Picture and Sound Reproducing Equipment.

tions, are recorded as a single jagged heavy line that looks like a succession of mountain peaks viewed from a distance.

Fig. 299 shows the combined picture and sound projector. In this, as in the Movietone, the light beam passes through the film on to a photo-electric cell. In this cell, the varying light gives rise to feeble variations of electric currents which are greatly magnified so as to operate a number of loud speakers on the stage. The machine is usually provided with an attachment whereby either the variable density (Movietone) film or the disc records (Vitaphone) may also be reproduced as sound.

379. **SPLICING FILM:** If the film in a Movietone or Photophone system should break while running through the projector, it must be carefully spliced. If the splice is not properly treated an objectionable loud thump startles the audience in the theatre, as a result of the electrical impulses sent into the



SOUND FILM SPLICE (QUIET)

Fig. 300

amplifier by the discontinuity on the sound track. Fig. 300, reproduced here from a drawing in the Movietone Bulletin, shows how this is obviated. The light is gradually shut off by a triangle painted with black or red lacquer (India ink is sometimes used) onto the sound track. The base of the wedge should be about $\frac{3}{8}$ inch long along the line of sprocket holes, while the apex is at the splice on the inner edge of the sound track. If the splice is covered by too short a triangle the change in light intensity will remain abrupt and more or less noise in reproduction will result. If too long a triangle is painted, on the other hand, enough of the track may be obliterated to cause an interruption in the record. Some care is, therefore, necessary. The painting is done on the celluloid side of the film.

REVIEW QUESTIONS.

1. Describe the Vitaphone (disc) method of synchronization of sound and scene.
2. Describe the Movietone (film) system.
3. What is the "wax," "play-back," "fader"?
4. Why are the moving picture cameras enclosed in sound proof booths when recording a sound picture?
5. Describe the process of reproduction by the Vitaphone system.
6. Describe the process of reproduction by the Movietone system.
7. How is synchronization accomplished and maintained between the moving picture projector and the sound disc in the Vitaphone system?
8. Describe the loud speakers used in sound picture reproduction. Where are they located and how are they arranged?
9. What is the function of the photo-electric cell in the Movietone reproducing system?
10. How should splices be made in sound-film to avoid objectionable noises?

CHAPTER 23

ANTENNAS

ANTENNAS—ANTENNA TYPES—ANTENNA INSULATION—LEAD-IN STRIP—WALL INSULATORS—GROUND—LIGHTNING ARRESTER—COUNTERPOISE—GROUNDS—LOOP ANTENNAS.

380. **ANTENNAS:** An antenna is simply a collector of the energy necessary to operate the radio receiver in a satisfactory manner. Therefore, it is of the utmost importance that the antenna collect as much of the energy from the passing electrostatic and electro-magnetic waves as possible, and then, having collected it, conserve it and deliver it to the radio set. Radio energy induced in an antenna continually seeks the shortest path to ground, hence, it is necessary that due precautions be taken to prevent any losses or leakage that will impair or lessen reception. As explained earlier in this book, the ordinary elevated wire antenna forms a condenser or capacity between it and the ground, and the signal currents flow in this circuit. Hence it is important that the total resistance of the circuit should be kept low if the maximum amount of current is to flow. This means that the antenna and ground connections must be well made, so as to have as low a resistance as possible.

381 **ANTENNA TYPES:** Antennas used for transmitting and receiving take a great number of forms, the use of any particular type usually depending on the particular conditions of receiving circuit and location.

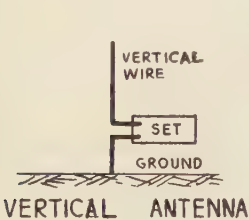


Fig. 301

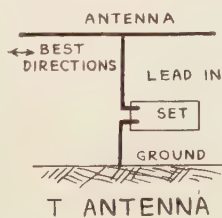


Fig. 302

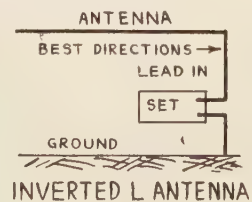


Fig. 303

Fig. 301 shows a simple vertical wire antenna. Antennas of this type transmit or receive equally well in all directions.

Fig. 302 shows a T type antenna. This consists of a vertical lead-in wire attached to the horizontal antenna wire at its center point. Antennas of this type transmit or receive best in the line of prolongation of the antenna, and equally in both directions.

Fig. 303 shows an inverted L antenna. This is the type most commonly used for reception. It receives and transmits best from the direction of the lead-in end.

Fig. 304 shows a V type antenna. This is used quite extensively for receiving. It transmits and receives best in the direction in which the V points.

Fig. 305 shows an umbrella type of antenna. This type has a very low resistance, and transmits and receives equally well in all directions.

Fig. 306 shows a loop antenna. This consists of a number of turns of wire

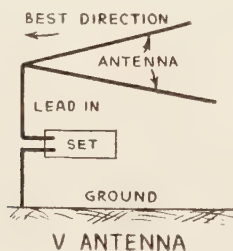


Fig. 304

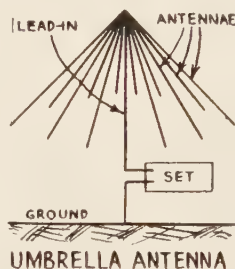
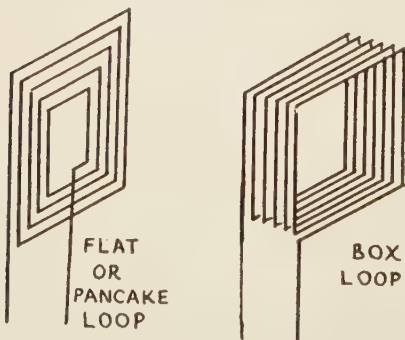


Fig. 305

mounted on a supporting frame as shown. This is used without a ground circuit and is extremely directional. It has maximum effect in the plane of the loop in either direction, and zero effect in a direction perpendicular to the plane of the loop.

382. **ANTENNA INSTALLATION:** The erection of an antenna is usually controlled by the available space and environment. It is perfectly easy to tell one just how an antenna should be erected but erecting it that way under



LOOP OR COIL ANTENNAE

Fig. 306



Photo Courtesy Cornish Wire Co.

Fig. 308—Receiving Antenna Kit.

all conditions is another story. Thus a big back yard offers a fine location provided there are no large metallic structures in the immediate vicinity. In a crowded location, such as an apartment house district, where one encounters numerous

difficulties in the presence of other antennae, and finds no obvious support for the contemplated one, the best judgment must be exercised.

The amount of energy that reaches the average receiving antenna is too small to be measured by any but the most sensitive measuring instruments. As the length of the antenna is decreased, the amount of energy picked up is also decreased. If it is increased the energy received increases but the tuning of the receiver usually becomes very broad. Hence a happy medium must be arrived at, and for good all around results on broadcast reception a single wire (solid, stranded, braided, or tape) measuring about 40 feet in the horizontal portion, 30 feet for the lead-in and 10 feet for the ground lead will serve the purpose very well. For short wave reception, antennas with a total length of 30 to 50 feet usually give very good results.

Number 12 or 14 solid or stranded copper wire is best for antenna wire as it has good conductivity, can be soldered, and is mechanically strong. Antenna

wire is procurable in 100 ft. rolls. Antennas can be supported by metal or wooden masts but should always be insulated at each end by suitable insulators. Fig. 307 shows a Pyrex glass insulator designed especially for ordinary receiving antennas. It is ribbed to increase the surface leakage path from one end to the other.

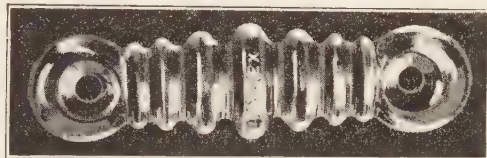


Photo Courtesy Corning Glass Co.

Fig. 307—Antenna Insulator

383. LEAD-IN STRIP: Where antenna lead-in wires are to be brought into the house, flat, flexible window lead-in strips can be used. These should be thoroughly waterproofed. The lead-in wires should be soldered to the strip terminals. The front of Fig. 308 shows a well made lead-in strip of this kind included in a complete receiving antenna kit.

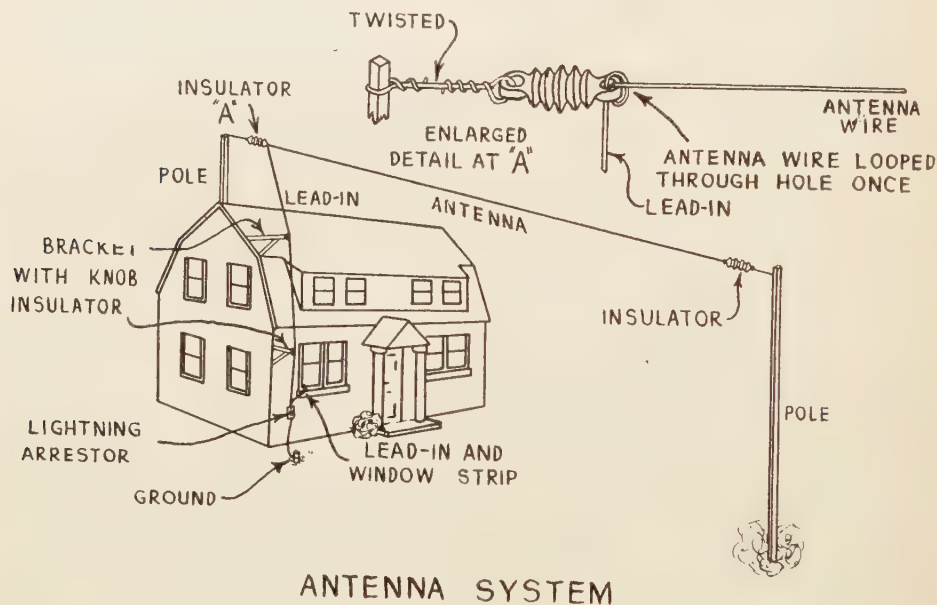
384. WALL INSULATOR: Fig. 309 shows a well installed antenna system. This should be studied carefully. If the antenna wire is continued down through the "house" insulator "A" as shown so as to also form the lead-in, it will not be necessary to make a joint at this point. The lead-in should be kept away from the house if possible. Where it is necessary to run it around the house to get to the other side, it should be supported with porcelain knob insulators.

385. GROUND: The ground wire should provide a connection to the earth of as low a resistance as possible and usually this may be accomplished most easily by connecting the wire to the cold water pipe if this is accessible. Water-pipe grounds are approved by the Fire Underwriters and they are far more efficient than the usual artificial or home made ground connections. Connection can be made to the water pipe by a simple ground clamp, as shown in Fig. 310. The pipe should be scraped bright and clean before attaching the clamp, to make sure of good electrical connection.

Where a city water pipe is not convenient for a ground connection, such articles as a radiator, metal object immersed in a stream or a well, etc., can be used. Gas pipes should never be used for ground connections. Counterpoise

grounds (explained later) can also be used in this case. In general, the more grounded objects one can connect the ground lead of a receiving set to, the better will be the reception.

386. **LIGHTNING ARRESTER:** An essential part of any radio installation is the lightning arrester, which should be connected in the circuit as indicated in the diagram of Fig. 311. The arrester should preferably be located



ANTENNA SYSTEM

Fig. 309

outside of the building at that point where the antenna lead-in enters the building. One terminal of the lightning arrester connects to the antenna and the other terminal connects to a good ground. A lightning arrester is a very simple device and actually consists of two metal electrodes which are spaced to within about five thousandths of an inch of each other. A radio-frequency current is too weak and too low in voltage to jump across these points which form the gap in the arrester and thence there is no path for the signal except that through the antenna to the receiver and thence to ground. The receiver is therefore actuated by this radio-frequency current and a signal is produced in the telephones, or the loud speaker, as the case may be. Suppose, however, that a high-potential atmospheric electrical discharge takes place near the antenna. Such discharges are always erratic in character and of high frequency. The antenna coil of the set therefore exerts a powerful choking action upon them even though the coil is quite small. For this reason, and also due to the very high voltage of the lightning discharge,

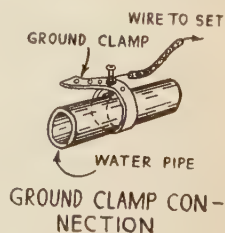


Fig. 310

if jumps across the small gap in the arrester and passes to ground without causing any more effect on the set than a loud static crash which will possibly drown out the signal for a moment.

Also, during electrical storms, or while they are approaching, there is a considerable amount of static electricity present in the atmosphere which tends to accumulate on the antenna system until such time as the voltage is high enough to jump across the small gap in the arrester. This discharge voltage is generally about 500 volts.

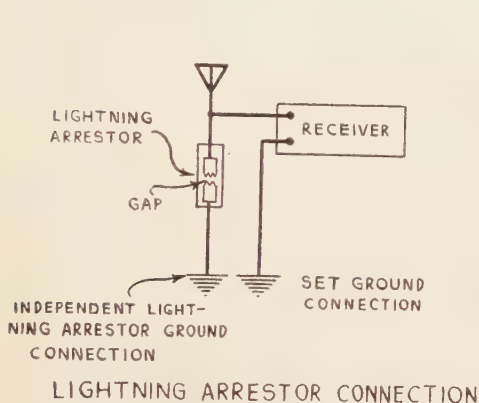


Fig. 311

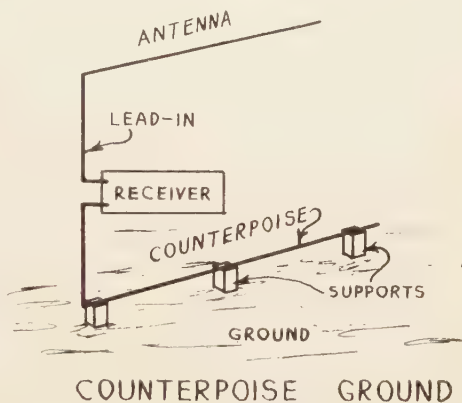


Fig. 312

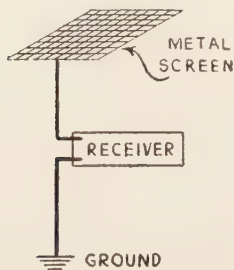
387. COUNTERPOISE GROUNDS: In places where it is difficult to secure a ground connection of good conductivity (as where the soil is dry and rocky and the ground water is at a considerable depth), a counterpoise ground can be used. This consists of another wire or system of wires supported a foot or two above the surface of the ground and insulated from it. The counterpoise should run parallel to the antenna and preferably under it. The receiving set is connected to the regular antenna and counterpoise ground as shown in Fig. 312. The counterpoise may consist of several wires, or a wire screen or net. It merely acts as one plate of the condenser with the aerial as the other plate. As it has good conductivity it works better than the high resistance ground even though its surface area is much smaller.

Counterpoise grounds are used extensively where regular ground connections are difficult or impossible to attain. Thus when operating a portable receiver in an automobile a short antenna can be installed in the roof of the car, and the frame of the car used as a counterpoise ground. The rubber tires insulate the frame from the earth. Aeroplanes usually use either a trailing wire antenna or an antenna mounted on insulated supports above the wings. The wing and fuselage bracing wires, motor frame, etc., are all connected together electrically with wire to form a counterpoise ground.

388. SCREEN ANTENNA: Fig. 313 shows a simple screen antenna which is becoming popular with the development of highly sensitive screen-grid receiving sets. This consists usually of a metallic plate or copper screen three or four feet square, which acts as the antenna or collector of energy. The screen

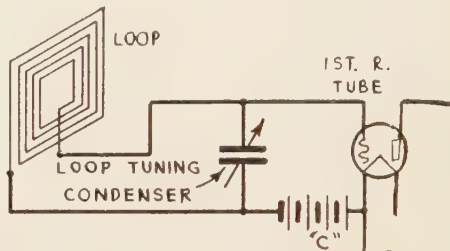
is usually enclosed in the cabinet with the receiver, and has the advantage of making it unnecessary to put up an outside antenna. Of course, the energy pick-up of such a small antenna is very small, and the set it is used with must be very sensitive.

389. LOOP ANTENNAS: Loop antennas generally consist of a rectangular or circular coil of from 1 to 15 or 20 turns of insulated wire wound on a supporting framework (see Fig. 306). This type of antenna operates solely



SCREEN ANTENNA

Fig. 313



LOOP ANTENNA CONNECTION

Fig. 314

on the magnetic waves sent out by the broadcast station. As these waves moving at high velocity cut across the plane of the loop they induce currents in the wires by electromagnetic induction. (The action is similar to the induction of current in the armature wires of a dynamo.) If the loop is turned so the waves strike it in its plane, the induced currents in the various turns are in such directions as to add to each other, thus giving maximum response. If the loop is turned at right angles to the advancing signal wave the currents in both halves are equal and opposite in direction and hence cancel each other. Hence there is no response. The current is induced due to the fact that by the time the wave has travelled from one side of the loop to the other side it has advanced through a part of its cycle, and so the phase relation of the induced currents in both sides of the loops differ.

Loop antennas have small pick-up unless made of large unwieldy size. They are operated with sensitive receivers such as super-heterodynes, etc. The loop is usually connected to the first tuning condenser of the receiver as shown in Fig. 314, for tuning. Consequently the loop should be designed so its inductance when worked with the particular tuning condenser to be used, will produce resonance over the entire waveband it is desired to receive.

The directional effects of loop antennas are made use of in radio direction finders and beam compasses.

REVIEW QUESTIONS.

1. What is the purpose of the antenna in a radio receiving system?
2. Explain the formation of a condenser between an elevated wire antenna and the ground.

3. Draw sketches of four types of antennas.
4. Draw a sketch and explain how to put up a horizontal inverted L antenna.
5. Why are insulators used on antennas? What desirable properties should antenna insulators have?
6. Explain why a low resistance ground connection is important for good reception. What steps should be taken to make the ground system of low resistance?
7. What is a counterpoise ground?
8. Describe a common form of lightning arrester, and show how it should be connected to a receiving antenna.
9. What is a loop antenna? Explain the principle of operation of the loop antenna.
10. In which direction does a loop antenna receive best? Why?

RADIO SYMBOLS.

The tremendous growth of the radio art has resulted in the invention of many new electrical devices unknown a few years ago. These, together with such well known things as coils, condensers, resistances, etc., make the total number of different parts used in radio receivers very large.

In order to represent these pieces of equipment in their proper relation in drawings and circuit diagrams, conventional symbols have been devised. It is unfortunate that no absolute standardization of radio symbols has been accepted in radio work up to the present time, but the following table contains most of the symbols which have become well known through more or less popular usage. In some cases where more than one symbol is commonly used for a piece of equipment, the several symbols are given.

These symbols have been used throughout this book, so it would be well for the reader to thoroughly acquaint himself with them, in order that he may thoroughly understand the diagrams.

(OVER)

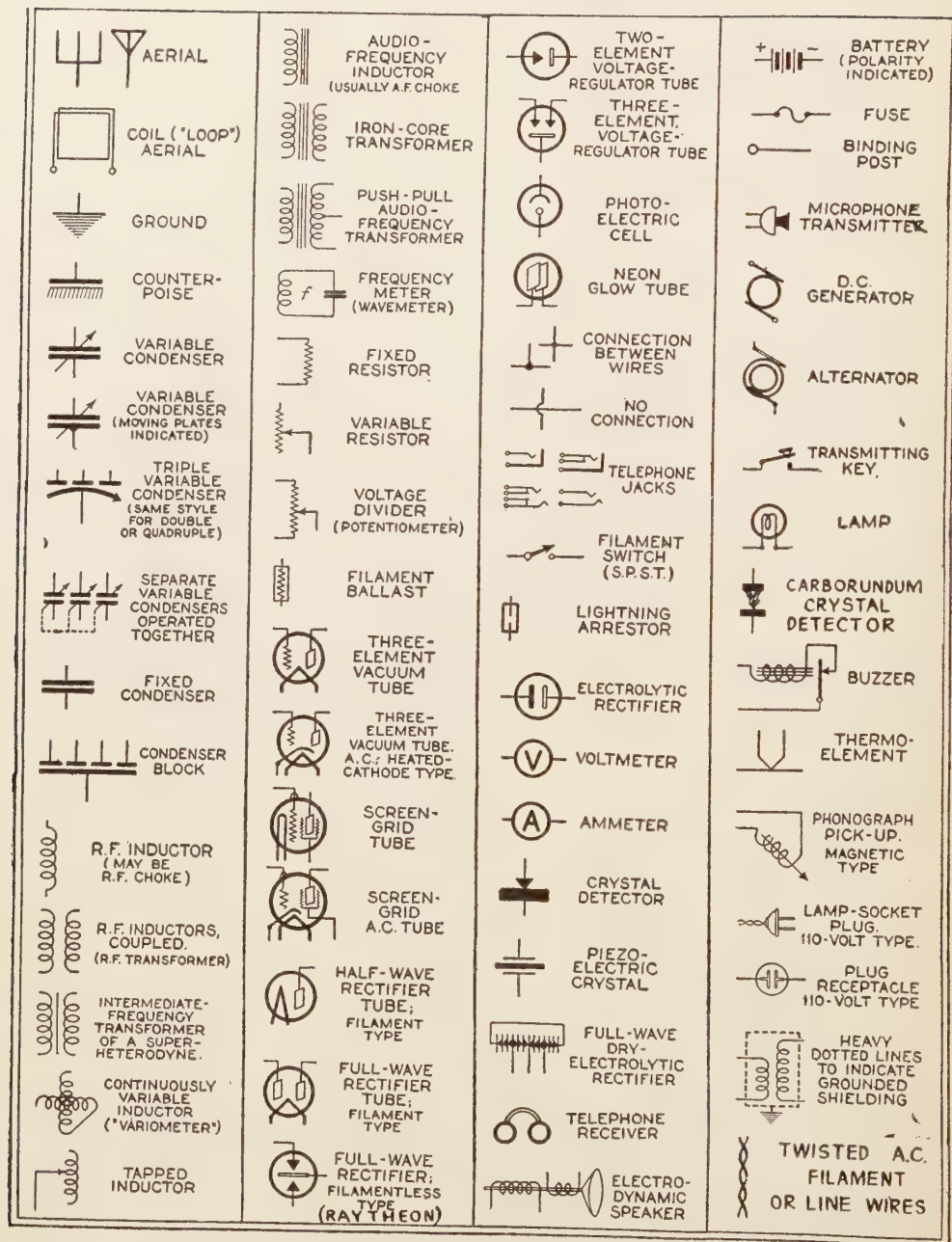


Fig. 315—Symbols Commonly Used in Radio Circuit Diagrams

PREFIXES USED IN RADIO WORK.

It happens that many of the units used extensively in electrical work are either too small or too large for convenient use in radio work. Instead of using large, cumbersome numbers to indicate the fractional or multiple parts of these units, it has become customary to make use of standard prefixes ahead of the original units, for simplifying calculations and avoiding many errors.

The student of radio should familiarize himself with these terms, so that he may become proficient in their understanding and use. A list of these prefixes is given below.

<i>Prefix</i>	<i>Meaning</i>
"deci":	one-tenth
"centi":	one-hundredth
"mil or milli":	one-thousandth
"micro":	one-millionth
"micro-micro":	one-millionth of one-millionth
"deka":	10 times
"hekta":	100 times
"kilo":	1,000 times
"mega":	1,000,000 times

Thus, "deci" means that the new unit is 0.1 of the original unit. A decimeter is 0.1 of a meter. A milliamper is 0.001 of an ampere. A microhenry is 0.000001 of a henry. A microfarad is 0.000001 of a farad. Instead of saying that a condenser has a capacity of 0.00035 microfarads we can say that it has a capacity of 350 micro-microfarads, etc.

A "centimeter" of inductance is equal to 0.001 of a microhenry. This unit does not follow the general rule.

The prefix "deka" means that the new unit is ten times the original unit. The prefix "kilo" means that the new unit is 1,000 times the original unit. Thus, one "kilocycle" equals 1,000 cycles. One "megohm" equals 1,000,000 ohms, etc.

APPENDIX C.

FORMULAE COMMONLY USED IN RADIO WORK.

Voltage, Current, Resistance

$$\text{Volts} = \text{Amperes} \times \text{Ohms} \quad (E = I \times R) \quad (1)$$

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \quad \left(I = \frac{E}{R} \right) \quad (2)$$

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}} \quad \left(R = \frac{E}{I} \right) \quad (3)$$

$$\text{Power: Watts} = \text{Volts} \times \text{Amperes} \quad (W = E \times I) \quad (4)$$

$$\text{Watts} = \text{Amperes squared} \times \text{ohms} \quad (W = I^2 R) \quad (5)$$

Resistances in Series: (all resistances in same units)

R is total resistance; R_1, R_2, R_3 , etc., are individual resistances.

$$R = R_1 + R_2 + R_3 \text{ etc.} \quad (6)$$

Resistances in Parallel: (all resistances must be in same units)

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{ etc.} \quad (7)$$

Capacity of Condensers in Series: (all capacities must be in same units)

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ etc.} \quad (8)$$

Capacity of Condensers in Parallel: (all capacities must be in same units)

$$C = C_1 + C_2 + C_3 \text{ etc.} \quad (9)$$

Impedance (Z) of A.C. Circuit Containing Inductance (L), Capacity (C) and Resistance (R). (frequency f).

$$Z = \sqrt{R^2 + (2 \times 3.1416 \times f \times L)^2 + \left(\frac{1}{2 \times 3.1416 \times f \times C} \right)^2}$$

Frequency and Wavelength Relations for radio (not for sound)

$$\text{Cycles} = \frac{300,000,000}{\text{meters (wavelength)}} \quad (11)$$

$$\text{Kilocycles} = \frac{300,000}{\text{meters (wavelength)}} \quad (12)$$

$$\text{Meters (wavelength)} = \frac{300,000,000}{\text{cycles}} \quad (13)$$

Wavelength at which resonance in a series tuned circuit takes place at given constants of inductance (L) and capacity (C)

$$\text{Meters (wavelength)} = 1.884 \sqrt{L \text{ microhenry} \times C \text{ (micro-microfarad)}} \quad (14)$$

$$\text{Meters (wavelength)} = 1884 \sqrt{L \text{ microhenry} \times C \text{ (microfarad)}} \quad (15)$$

Frequency at which resonance takes place with given constants of inductance and capacity.

$$\text{Cycles} = \frac{159,200}{\sqrt{L \text{ (microhenry)} \times C \text{ (microfarad)}}} \quad (16)$$

$$= \frac{159,200,000}{\sqrt{L \text{ (microhenry)} \times C \text{ (micro-microfarad)}}} \quad (17)$$

WAVELENGTH—FREQUENCY CONVERSION CHART

Radio engineers started so long ago to think and calculate in terms of wavelength (meters) that no one remembers just why they started that way. Today, however, with the governments of all countries allocating transmitting stations by definite frequency separations (in kilocycles), it is much more convenient and accurate to work in terms of frequency.

This new habit, unfortunately, is not easy to acquire, because the kilocycle difference per wavelength is very great at short wavelengths (that is, below about 50 meters), and very small at the usual broadcast wavelengths, between 200 and 550 meters.

The relation between frequency and wavelength is this: radio waves travel at the same speed as light, approximately 300,000,000 meters per second. This corresponds to about 186,000 miles per second. If the wavelength of a particular transmitting station, for instance, is 100 meters, each wave will travel 100 meters before the next one starts. During one second there will be time for 3,000,000 such waves. In other words,

$$\text{Frequency (in cycles)} = \frac{300,000,000}{\text{Wavelength (in meters)}}$$

In general, the frequency as expressed in cycles is a large and unwieldy number, so radio engineers use the term "kilocycle," which stands for one thousand cycles. Thus, instead of saying 1,000,000 cycles (equivalent to 300 meters), we say 1,000 kilocycles. The term is usually abbreviated into the letters "kc." On the very short wavelengths the frequency runs up into several million cycles, so the term "megacycles," meaning one million cycles, is frequently found to be more convenient than "kilocycles."

Nowadays we work in terms of frequency rather than wavelength because it has been found that a uniform separation between stations of ten kilocycles is enough to prevent the transmitters from causing interference with each other in receiving sets. There is no way of expressing this separation as a uniform quantity in terms of wavelength. For example, the difference between 590 to 600 meters is approximately 10 kilocycles, while the difference between 10 meters and 20 meters is 15,000 kilocycles.

The chart on page 351 was prepared to enable you to tell at a glance the relation between frequency separation, as expressed in kilocycles and wavelength, as expressed in meters. By referring to the numerals in the right-hand column of the chart, you will see that 600 meters is equal to 500 kilocycles, while 200 meters is equal to 1,500 cycles.

The chart discloses one very interesting fact that many people do not appreciate. If we take the range from 200 to 500 meters, for broadcasting, we find it equal to a band 900 kilocycles wide. This means it is big enough to accommodate ninety transmitting bands or "channels" each 10 kilocycles wide. In the space between 10 meters and 200 meters (a band only 190 meters wide compared to 300 meters for the 200-500 range) there is a frequency difference of 28,500 kilocycles.

which will give us 2,850 ten-kilocycle channels. In other words, between 10 and 200 meters there is room for 32 times as many broadcasting stations as between 200 and 500 meters. There is room for even a greater number of code stations, since they do not require as much frequency separation as broadcasting-stations. When you consider this you will realize why short waves have assumed such a tremendous commercial importance, with many different communication companies asking for more channels than there are available.

Even though you are not in the habit of thinking in terms of frequency, when you read that the band between 6,000 and 6,150 kilocycles is reserved for short-wave broadcasting you can look at the chart, find 6,000 kc., and, following the line from left to right, see that this refers to a space between 50 meters and about 51 meters. Then you will realize that, although the wavelength separation is only one meter, the band has fifteen 10-kilocycle bands, or room for one-sixth as many stations as can operate between 200 and 500 meters.

Again, the band between 28,000 and 30,000 kc. has been assigned to amateurs and experimenters. Here is a separation of only .7 meters, yet there are two hundred 10-kc. bands in what appears to be a very small space in the ether.

It is suggested that all radio experimenters make use of this chart to accustom themselves as quickly as possible to kilocycles in referring to transmitting stations, for only then will we have an accurate idea of the places for each station in the method of allocation now in use throughout the world.

KILOCYCLE-METER CONVERSION TABLE

The Kilocycle-Meter Conversion Table which follows on page 352, is reproduced here from Publication of the Bureau of Standards No. 67, by courtesy of the Bureau of Standards. This table gives accurate values of kilocycles corresponding to any number of meters and vice versa. The table is based on the factor 299,820 (which is the exact conversion factor, 300,000 being used for approximate calculation) and gives values for every 10 kilocycles or meters. The table is entirely reversible; that is, for example, 50 kilocycles is 5.996 meters, and also 50 meters is 5.996 kilocycles, etc. The range of the table is easily extended by shifting the decimal point; the shift is in opposite directions for each pair of values; for example, one cannot find 223 in the first column, but its equivalent is obtained by finding later in the table that 2,230 kilocycles or meters is equivalent to 134.4 meters or kilocycles, from which 223 kilocycles or meters is equivalent to 1,344 meters or kilocycles.

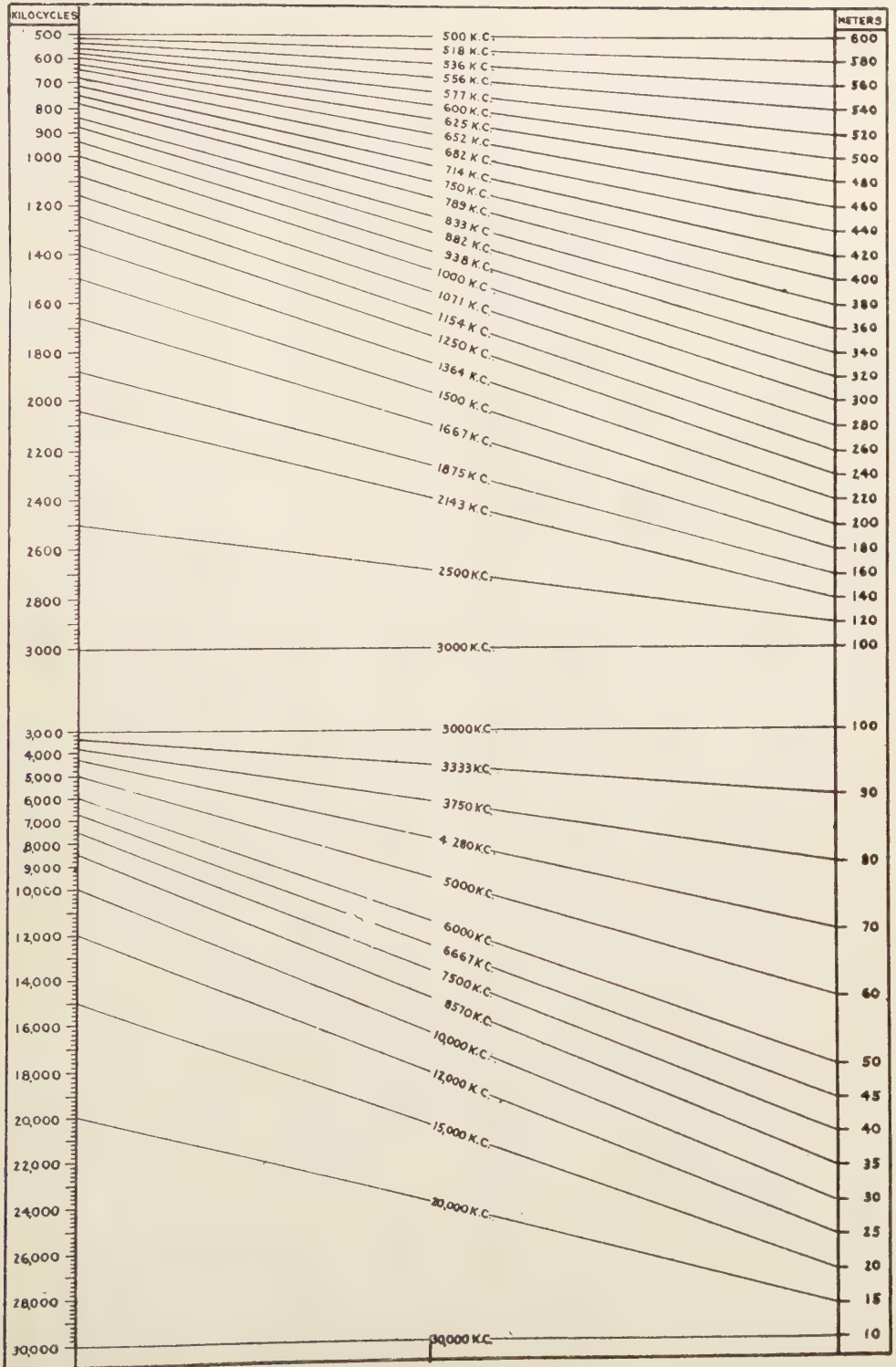


Fig. 316—Wavelength Frequency Relation Chart.

KILOCYCLES (kc) TO METERS (m), OR METERS TO KILOCYCLES
[Columns Are Interchangeable]

kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc
10	29,982	510	587.9	1,010	296.9	1,510	108.6	2,010	149.2
20	14,991	520	576.6	1,020	293.9	1,520	107.2	2,020	148.4
30	9,994	530	565.7	1,030	291.1	1,530	196.0	2,030	147.7
40	7,496	540	555.2	1,040	288.3	1,540	194.7	2,040	147.0
50	5,996	550	545.1	1,050	285.5	1,550	193.4	2,050	146.3
60	4,997	560	535.4	1,060	282.8	1,560	192.2	2,060	145.5
70	4,283	570	526.0	1,070	280.2	1,570	191.0	2,070	144.8
80	3,748	580	516.9	1,080	277.6	1,580	189.8	2,080	144.1
90	3,331	590	508.2	1,090	275.1	1,590	188.6	2,090	143.5
100	2,998	600	499.7	1,100	272.6	1,600	187.4	2,100	142.8
110	2,726	610	491.5	1,110	270.1	1,610	186.2	2,110	142.1
120	3,499	620	483.6	1,120	267.7	1,620	185.1	2,120	141.4
130	2,306	630	475.9	1,130	265.3	1,630	183.9	2,130	140.8
140	2,142	640	468.5	1,140	263.0	1,640	182.8	2,140	140.1
150	1,999	650	461.3	1,150	260.7	1,650	181.7	2,150	139.5
160	1,874	660	454.3	1,160	258.5	1,660	180.6	2,160	138.8
170	1,764	670	447.5	1,170	256.3	1,670	179.5	2,170	138.1
180	1,666	680	440.9	1,180	254.1	1,680	178.5	2,180	137.5
190	1,578	690	434.5	1,190	252.0	1,690	177.4	2,190	136.9
200	1,499	700	428.3	1,200	249.9	1,700	176.4	2,200	136.3
210	1,428	710	422.3	1,210	247.8	1,710	175.3	2,210	135.7
220	1,363	720	416.4	1,220	245.8	1,720	174.3	2,220	135.1
230	1,304	730	410.7	1,230	243.8	1,730	173.3	2,230	134.4
240	1,249	740	405.2	1,240	241.8	1,740	172.3	2,240	133.8
250	1,199	750	399.8	1,250	239.9	1,750	171.3	2,250	133.3
260	1,153	760	394.5	1,260	238.0	1,760	170.4	2,260	132.7
270	1,110	770	389.4	1,270	236.1	1,770	169.4	2,270	132.1
280	1,071	780	384.4	1,280	234.2	1,780	168.4	2,280	131.5
290	1,034	790	379.5	1,290	232.4	1,790	167.5	2,290	130.9
300	999.4	800	374.8	1,300	230.6	1,800	166.6	2,300	130.4
310	967.2	810	370.2	1,310	228.9	1,810	165.6	2,310	129.8
320	967.9	820	365.6	1,320	227.1	1,820	164.7	2,320	129.2
330	908.6	830	361.2	1,330	225.4	1,830	163.8	2,330	128.7
340	881.8	840	356.9	1,340	223.7	1,840	162.9	2,340	128.1
350	856.6	850	352.7	1,350	222.1	1,850	162.1	2,350	127.6
360	832.8	860	348.6	1,360	220.4	1,860	161.2	2,360	127.0
370	810.3	870	344.6	1,370	218.8	1,870	160.3	2,370	126.5
380	789.0	880	340.7	1,380	217.3	1,880	159.5	2,380	126.0
390	768.8	890	336.9	1,390	215.7	1,890	158.6	2,390	125.4
400	749.6	900	333.1	1,400	214.2	1,900	157.8	2,400	124.9
410	731.3	910	329.5	1,410	212.6	1,910	157.0	2,410	124.4
420	713.9	920	325.9	1,420	211.1	1,920	156.2	2,420	123.9
430	697.3	930	322.4	1,430	209.7	1,930	155.3	2,430	123.4
440	681.4	940	319.0	1,440	208.2	1,940	154.5	2,440	122.9
450	666.3	950	315.6	1,450	206.8	1,950	153.8	2,450	122.4
460	651.8	960	312.3	1,460	205.4	1,960	153.0	2,460	121.9
470	637.9	970	309.1	1,470	204.0	1,970	152.2	2,470	121.4
480	624.6	980	303.9	1,480	202.6	1,980	151.4	2,480	120.9
490	611.9	990	302.8	1,490	201.2	1,990	150.7	2,490	120.4
500	599.6	1,000	299.8	1,500	199.9	2,000	149.9	2,500	119.9

KILOCYCLES (kc) TO METERS (m), OR METERS TO KILOCYCLES
(Cont'd) [Columns Are Interchangeable]

kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc
2,510	119.5	3,010	99.61	3,510	85.42	4,010	74.77	4,510	66.48
2,520	119.0	3,020	99.28	3,520	85.18	4,020	74.58	4,520	66.33
2,530	118.5	3,030	98.95	3,530	84.94	4,030	74.40	4,530	66.19
2,540	118.0	3,040	98.62	3,540	84.70	4,040	74.21	4,540	66.04
2,550	117.6	3,050	98.30	3,550	84.46	4,050	74.03	4,550	65.89
2,560	117.1	3,060	97.98	3,560	84.22	4,060	73.85	4,560	65.75
2,570	116.7	3,070	97.66	3,570	83.98	4,070	73.67	4,570	65.61
2,580	116.2	3,080	97.34	3,580	83.75	4,080	73.49	4,580	65.46
2,590	115.8	3,090	97.03	3,590	83.52	4,090	73.31	4,590	65.32
2,600	115.3	3,100	96.72	3,600	83.28	4,100	73.13	4,600	65.18
2,610	114.9	3,110	96.41	3,610	83.05	4,110	72.95	4,610	65.04
2,620	114.4	3,120	96.10	3,620	82.82	4,120	72.77	4,620	64.90
2,630	114.0	3,130	95.79	3,630	82.60	4,130	72.60	4,630	64.76
2,640	113.6	3,140	95.48	3,640	82.37	4,140	72.42	4,640	64.62
2,650	113.1	3,150	95.18	3,650	82.14	4,150	72.25	4,650	64.48
2,660	112.7	3,160	94.88	3,660	81.92	4,160	72.07	4,660	64.34
2,670	112.3	3,170	94.58	3,670	81.70	4,170	71.90	4,670	64.20
2,680	111.9	3,180	94.28	3,680	81.47	4,180	71.73	4,680	64.06
2,690	111.5	3,190	93.99	3,690	81.25	4,190	71.56	4,690	63.93
2,700	111.0	3,200	93.69	3,700	81.03	4,200	71.30	4,700	63.79
2,710	110.6	3,210	93.40	3,710	80.81	4,210	71.22	4,710	63.66
2,720	110.2	3,220	93.11	3,720	80.60	4,220	71.05	4,720	63.52
2,730	109.8	3,230	92.82	3,730	80.38	4,230	70.88	4,730	63.39
2,740	109.4	3,240	92.54	3,740	80.17	4,240	70.71	4,740	63.25
2,750	109.0	3,250	92.25	3,750	79.95	4,250	70.55	4,750	63.12
2,760	108.6	3,260	91.97	3,760	79.74	4,260	70.38	4,760	62.99
2,770	108.2	3,270	91.69	3,770	79.53	4,270	70.22	4,770	62.86
2,780	107.8	3,280	91.41	3,780	79.32	4,280	70.05	4,780	62.72
2,790	107.5	3,290	91.13	3,790	79.11	4,290	69.89	4,790	62.59
2,800	107.1	3,300	90.86	3,800	78.90	4,300	69.73	4,800	62.46
2,810	106.7	3,310	90.58	3,810	78.69	4,310	69.56	4,810	62.33
2,820	106.3	3,320	90.31	3,820	78.49	4,320	69.40	4,820	62.20
2,830	105.9	3,330	90.04	3,830	78.28	4,330	69.24	4,830	62.07
2,840	105.6	3,340	89.77	3,840	78.08	4,340	69.08	4,840	61.95
2,850	105.2	3,350	89.50	3,850	77.88	4,350	68.92	4,850	61.82
2,860	104.8	3,360	89.23	3,860	77.67	4,360	68.77	4,860	61.69
2,870	104.5	3,370	88.97	3,870	77.47	4,370	68.61	4,870	61.56
2,880	104.1	3,380	88.70	3,880	77.27	4,380	68.45	4,880	61.44
2,890	103.7	3,390	88.44	3,890	77.07	4,390	68.30	4,890	61.31
2,900	103.4	3,400	88.18	3,900	76.88	4,400	68.14	4,900	61.19
2,910	103.0	3,410	87.92	3,910	76.68	4,410	67.99	4,910	61.06
2,920	102.7	3,420	87.67	3,920	76.48	4,420	67.83	4,920	60.94
2,930	102.3	3,430	87.41	3,930	76.29	4,430	67.68	4,930	60.82
2,940	102.0	3,440	87.16	3,940	76.10	4,440	67.53	4,940	60.69
2,950	101.6	3,450	86.90	3,950	75.90	4,450	67.38	4,950	60.57
2,960	101.3	3,460	96.65	3,960	75.51	4,460	67.22	4,960	60.45
2,970	100.9	3,470	86.40	3,970	75.52	4,470	67.07	4,970	60.33
2,980	100.6	3,480	86.16	3,980	75.33	4,480	66.92	4,980	60.20
2,990	100.3	3,490	85.91	3,990	75.14	4,490	66.78	4,990	60.08
3,000	99.94	3,500	85.66	4,000	74.96	4,500	66.63	5,000	59.96

KILOCYCLES (kc) TO METERS (m), OR METERS TO KILOCYCLES
(Cont'd) [Columns Are Interchangeable]

kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc
5,010	59.84	5,510	54.41	6,010	49.89	6,510	46.06	7,010	42.77
5,020	59.73	5,520	54.32	6,020	49.80	6,520	45.98	7,020	42.71
5,030	59.61	5,530	54.22	6,030	49.72	6,530	45.91	7,030	42.65
5,040	59.49	5,540	54.12	6,040	49.64	6,540	45.84	7,040	42.59
5,050	59.37	5,550	54.02	6,050	49.56	6,550	45.77	7,050	42.53
5,060	59.25	5,560	53.92	6,060	49.48	6,560	45.70	7,060	42.47
5,070	59.13	5,570	53.83	6,070	49.39	6,570	45.63	7,070	42.41
5,080	59.02	5,580	53.73	6,080	49.31	6,580	45.57	7,080	42.35
5,090	58.90	5,590	53.64	6,090	49.23	6,590	45.50	7,090	42.29
5,100	58.79	5,600	53.54	6,100	49.15	6,600	45.43	7,100	42.23
5,110	58.67	5,610	53.44	6,110	49.07	6,610	45.36	7,110	42.17
5,120	58.56	5,620	53.35	6,120	48.99	6,620	45.29	7,120	42.11
5,130	58.44	5,630	53.25	6,130	48.91	6,630	45.22	7,130	42.05
5,140	58.33	5,640	53.16	6,140	48.83	6,640	45.15	7,140	41.99
5,150	58.22	5,650	53.07	6,150	48.75	6,650	45.09	7,150	41.93
5,160	58.10	5,660	52.97	6,160	48.67	6,660	45.02	7,160	41.87
5,170	57.99	5,670	52.88	6,170	48.59	6,670	44.95	7,170	41.82
5,180	57.88	5,680	52.79	6,180	48.51	6,680	44.88	7,180	41.76
5,190	57.77	5,690	52.69	6,190	48.44	6,690	44.82	7,190	41.70
5,200	57.66	5,700	52.60	6,200	48.36	6,700	44.75	7,200	41.64
5,210	57.55	5,710	52.51	6,210	48.28	6,710	44.68	7,210	41.58
5,220	57.44	5,720	52.42	6,220	48.20	6,720	44.62	7,220	41.53
5,230	57.33	5,730	52.32	6,230	48.13	6,730	44.55	7,230	41.47
5,240	57.22	5,740	52.23	6,240	48.05	6,740	44.48	7,240	41.41
5,250	57.11	5,750	52.14	6,250	47.97	6,750	44.42	7,250	41.35
5,260	57.00	5,760	52.05	6,260	47.89	6,760	44.35	7,260	41.30
5,270	56.89	5,770	51.96	6,270	47.82	6,770	44.29	7,270	41.24
5,280	56.78	5,780	51.87	6,280	47.74	6,780	44.22	7,280	41.18
5,290	56.68	5,790	51.78	6,290	47.67	6,790	44.16	7,290	41.13
5,300	56.57	5,800	51.69	6,300	47.59	6,800	44.09	7,300	41.07
5,310	56.46	5,810	51.60	6,310	47.52	6,810	44.03	7,310	41.02
5,320	56.36	5,820	51.52	6,320	47.44	6,820	43.96	7,320	40.96
5,330	56.25	5,830	51.43	6,330	47.36	6,830	43.90	7,330	40.90
5,340	56.15	5,840	51.34	6,340	47.29	6,840	43.83	7,340	40.85
5,350	56.04	5,850	51.25	6,350	47.22	6,850	43.77	7,350	40.79
5,360	55.94	5,860	51.16	6,360	47.14	6,860	43.71	7,360	40.74
5,370	55.83	5,870	51.08	6,370	47.07	6,870	43.64	7,370	40.68
5,380	55.73	5,880	50.99	6,380	46.99	6,880	43.58	7,380	40.63
5,390	55.63	5,890	50.90	6,390	46.92	6,890	43.52	7,390	40.57
5,400	55.52	5,900	50.82	6,400	46.85	6,900	43.45	7,400	40.52
5,410	55.42	5,910	50.73	6,410	46.77	6,910	43.39	7,410	40.46
5,420	55.32	5,920	50.65	6,420	46.70	6,920	43.33	7,420	40.41
5,430	55.22	5,930	50.56	6,430	46.63	6,930	43.26	7,430	40.35
5,440	55.11	5,940	50.47	6,440	46.56	6,940	43.20	7,440	40.30
5,450	55.01	5,950	50.39	6,450	46.48	6,950	43.14	7,450	40.24
5,460	54.91	5,960	50.31	6,460	46.41	6,960	43.08	7,460	40.19
5,470	54.81	5,970	50.22	6,470	46.34	6,970	43.02	7,470	40.14
5,480	54.71	5,980	50.14	6,480	46.27	6,980	42.95	7,480	40.08
5,490	54.61	5,990	50.05	6,490	46.20	6,990	42.89	7,490	40.03
5,500	54.51	6,000	49.97	6,500	46.13	7,000	42.83	7,500	39.98

KILOCYCLES (kc) TO METERS (m), OR METERS TO KILOCYCLES
(*Cont'd*) [Columns Are Interchangeable]

<i>kc or m</i>	<i>m or kc</i>	<i>kc or m</i>	<i>m or kc</i>	<i>kc or m</i>	<i>m or kc</i>	<i>kc or m</i>	<i>m or kc</i>	<i>kc or m</i>	<i>m or kc</i>
7,510	39.92	8,010	37.43	8,510	35.23	9,010	33.28	9,510	31.53
7,520	39.87	8,020	37.38	8,520	35.19	9,020	33.24	9,520	31.49
7,530	39.82	8,030	37.34	8,530	35.15	9,030	33.20	9,530	31.46
7,540	39.76	8,040	37.29	8,540	35.11	9,040	33.17	9,540	31.43
7,550	39.71	8,050	37.24	8,550	35.07	9,050	33.13	9,550	31.39
7,560	39.66	8,060	37.20	8,560	35.03	9,060	33.09	9,560	31.36
7,570	39.61	8,070	37.15	8,570	34.98	9,070	33.06	9,570	31.33
7,580	39.55	8,080	37.11	8,580	34.94	9,080	33.02	9,580	31.30
7,590	39.50	8,090	37.06	8,590	34.90	9,090	32.98	9,590	31.26
7,600	39.45	8,100	37.01	8,600	34.86	9,100	32.95	9,600	31.23
7,610	39.40	8,110	36.97	8,610	34.82	9,110	32.91	9,610	31.20
7,620	39.35	8,120	36.92	8,620	34.78	9,120	32.88	9,620	31.17
7,630	39.29	8,130	36.88	8,630	34.74	9,130	32.84	9,630	31.13
7,640	39.24	8,140	36.83	8,640	34.70	9,140	32.80	9,640	31.10
7,650	39.19	8,150	36.79	8,650	34.66	9,150	32.77	9,650	31.07
7,660	39.14	8,160	36.74	8,660	34.62	9,160	32.73	9,660	31.04
7,670	39.09	8,170	36.70	8,670	34.58	9,170	32.70	9,670	31.01
7,680	39.04	8,180	36.65	8,680	34.54	9,180	32.66	9,680	30.97
7,690	38.99	8,190	36.61	8,690	34.50	9,190	32.62	9,690	30.94
7,700	38.04	8,200	36.56	8,700	34.46	9,200	32.59	9,700	30.91
7,710	38.89	8,210	36.52	8,710	34.42	9,210	32.55	9,710	30.88
7,720	38.84	8,220	36.47	8,720	34.38	9,220	32.52	9,720	30.85
7,730	38.79	8,230	36.43	8,730	34.34	9,230	32.48	9,730	30.81
7,740	38.74	8,240	36.39	8,740	34.30	9,240	32.45	9,740	30.78
7,750	38.69	8,250	36.34	8,750	34.27	9,250	32.41	9,750	30.75
7,760	38.64	8,260	36.30	8,760	34.23	9,260	32.38	9,760	30.72
7,770	38.59	8,270	36.25	8,770	34.19	9,270	32.34	9,770	30.69
7,780	38.54	8,280	36.21	8,780	34.15	9,280	32.31	9,780	30.66
7,790	38.49	8,290	36.17	8,790	34.11	9,290	32.27	9,790	30.63
7,800	38.44	8,300	36.12	8,800	34.07	9,300	32.24	9,800	30.59
7,810	38.39	8,310	36.08	8,810	34.03	9,310	32.20	9,810	30.56
7,820	38.34	8,320	36.04	8,820	33.99	9,320	32.17	9,820	30.53
7,830	38.29	8,330	35.99	8,830	33.95	9,330	32.14	9,830	30.50
7,840	38.24	8,340	35.95	8,840	33.92	9,340	32.10	9,840	30.47
7,850	38.19	8,350	35.91	8,850	33.88	9,350	32.07	9,850	30.44
7,860	38.14	8,360	35.86	8,860	33.84	9,360	32.03	9,860	30.41
7,870	38.10	8,370	35.82	8,870	33.80	9,370	32.00	9,870	30.38
7,880	38.05	8,380	35.78	8,880	33.76	9,380	31.96	9,880	30.35
7,890	38.00	8,390	35.74	8,890	33.73	9,390	31.93	9,890	30.32
7,900	37.95	8,400	35.69	8,900	33.69	9,400	31.90	9,900	30.28
7,910	37.90	8,410	35.65	8,910	33.65	9,410	31.86	9,910	30.25
7,920	37.86	8,420	35.61	8,920	33.61	9,420	31.83	9,920	30.22
7,930	37.81	8,430	35.57	8,930	33.57	9,430	31.79	9,930	30.19
7,940	37.76	8,440	35.52	8,940	33.54	9,440	31.76	9,940	30.16
7,950	37.71	8,450	35.48	8,950	33.50	9,450	31.73	9,950	30.13
7,960	37.67	8,460	35.44	8,960	33.46	9,460	31.69	9,960	30.10
7,970	37.62	8,470	35.40	8,970	33.42	9,470	31.66	9,970	30.07
7,980	37.57	8,480	35.36	8,980	33.39	9,480	31.63	9,980	30.04
7,990	37.52	8,490	35.31	8,990	33.35	9,490	31.59	9,990	30.01
8,000	37.48	8,500	35.27	9,000	33.31	9,500	31.56	10,000	29.98

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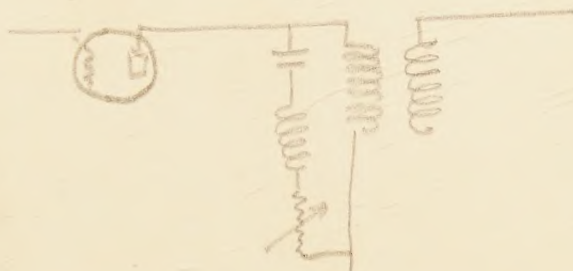
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Equalizer



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$$8^2 = 512$$

$$24^2 = 576$$

$$\begin{array}{r} 3.14 \\ 15 \\ \hline 1570 \\ 314 \\ \hline 12 \overline{) 4710} \end{array}$$

$$32 \overline{) 1100} \left(34 \div 4 = 8 \frac{1}{2} \right)$$
$$\begin{array}{r} 96 \\ \hline 140 \\ 128 \\ \hline \end{array}$$

7600

$$\begin{array}{r} 30 \\ 20 \\ \hline 900 \end{array}$$

$$\begin{array}{r} 25 \\ 25 \\ \hline 125 \\ 50 \\ \hline 625 \end{array} \quad \begin{array}{r} 27 \\ 27 \\ \hline 189 \\ 54 \\ \hline 729 \end{array}$$

42 mm 15" dia
 $\frac{4}{6.8}$ M. approx

$$\begin{array}{r} 22 \\ 5 \\ \hline 176 \end{array}$$

9-3
30



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